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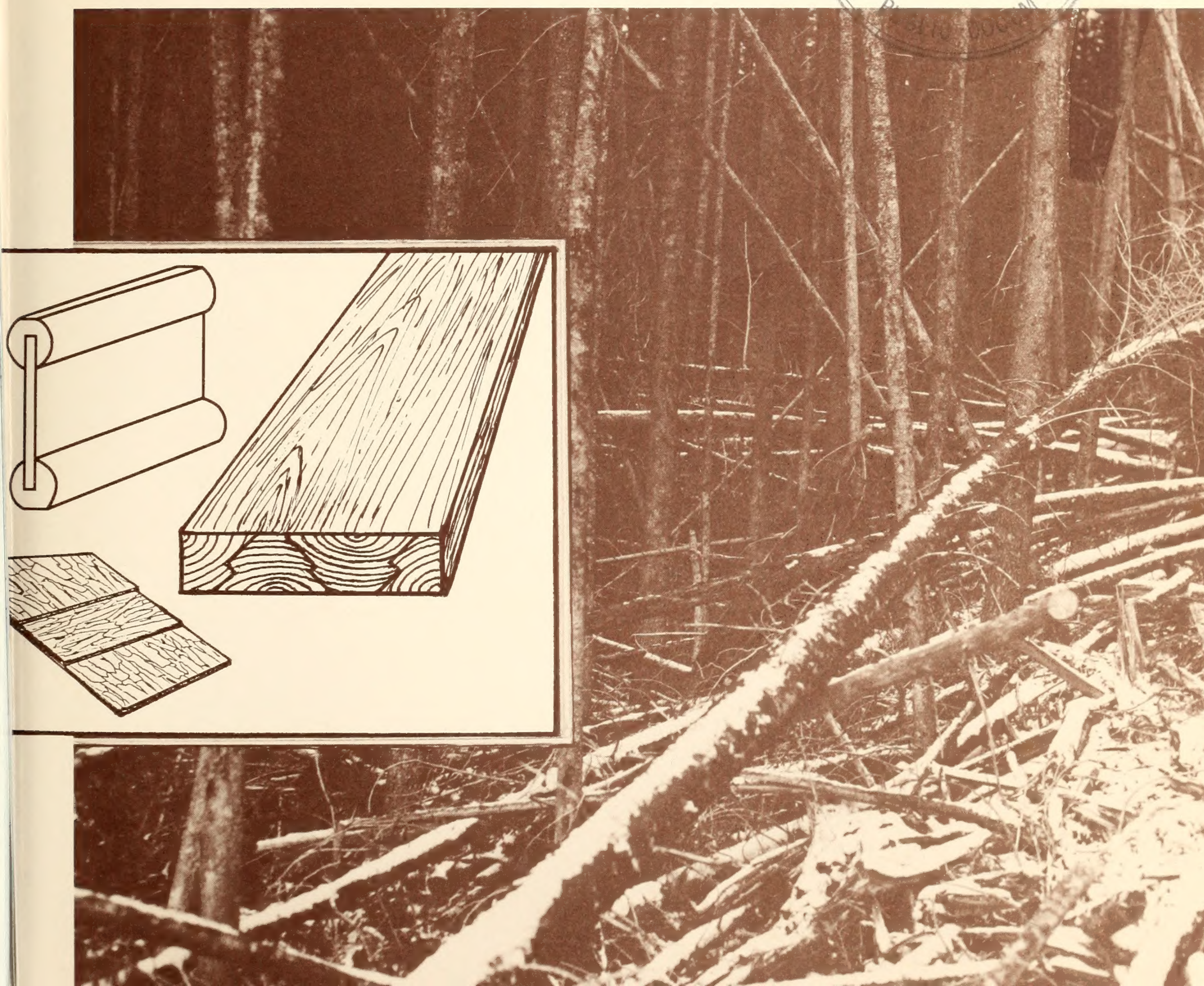
Proposed Wood Products Plant To Utilize Sub-Sawlog Size and Dead Lodgepole Pine in Northwestern Montana— A Technical and Economic Feasibility Analysis

Peter Koch
Charles E. Keegan III
Edwin J. Burke
Darrell L. Brown



THE AUTHORS

PETER KOCH is President, Wood Science Laboratory, Inc., Corvallis, MT.

CHARLES E. KEEGAN III is Director of Forest Industry Research, Bureau of Business and Economic Research, University of Montana, Missoula.

EDWIN J. BURKE is Associate Professor of Wood Science and Associate Dean, School of Forestry, University of Montana, Missoula.

DARRELL L. BROWN is Assistant Professor, School of Business Administration, University of Montana, Missoula.

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Intermountain Research Station
324 25th Street
Ogden, UT 84401

RESEARCH SUMMARY

This report proposes—and evaluates the technical and economic feasibility of—an integrated multiproduct facility designed to utilize small-diameter (sub-sawtimber size) lodgepole pine in the Libby-Troy area of northwestern Montana. Harvesting and silvicultural activities related to the manufacturing operation are designed to help solve a major public forest management problem in the area by removing—at minimal public cost—stands of stagnated, bark-beetle-infested, and dead timber to facilitate rapid regeneration into vigorous new stands of greatly increased productivity.

The facility is designed to employ 271 people in the manufacturing plant to process 200,000 tons (ovendry-weight basis) of stemwood annually. Trees harvested will be predominantly lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) in diameter classes from 3 to 7 inches. Some associated species will also be harvested. Several manufacturing centers will be integrated in the plant to produce the following products:

- market OSB (oriented-strand board)
- fabricated joists with webs of waferboard (structural flakeboard with randomly oriented flakes) and flanges of minimally machined lodgepole pine dowels
- edge-glued lumber panels for mill work
- studs
- tree props and fence rails
- pulp chips
- particleboard furnish

The facility will generate an estimated $40 million in revenue in its first year of full production and will operate for 20 years. It will require $62 million in capital and have annual operating costs before depreciation of $30 million at full production.

Major Products and Markets

The plant will use small-diameter lodgepole pine timber to manufacture fabricated and reconstituted products for uses historically filled by large-diameter old-growth timber, the supply of which is forecast to diminish in quality as well as quantity at the same time that consumption of wood products is projected to increase significantly. Specifically, the plant is designed to receive 90 percent of its revenue from three products—market OSB, fabricated joists, and edge-glued lumber panels.

The OSB is a structural panel made from 3-inch-long wood flakes about twice the thickness of a postage stamp, oriented in the panel to achieve maximum stiffness and strength. It has wide and growing application in residential and nonresidential construction and in industrial markets.

The fabricated joists will be made with flanges of lodgepole pine dowels $2^{5}/_{8}$ inches in diameter and webs of $^{3}/_{8}$-inch-thick waferboard. They will be manufactured in depths of 10, 12, 14, and 16 inches and designed for uses currently filled by solid-sawn 2 by 10 and 2 by 12 softwood structural lumber or by joists fabricated with solid-sawn lumber or parallel-laminated veneer flanges and plywood webs. Joists fabricated with minimally machined lodgepole pine dowels for flanges are lighter, drier, stiffer, stronger, and more uniform in mechanical properties than sawn lumber joists of comparable depth. A major advantage is quick availability from distributing yards in schedules of precise but nonstandard lengths (up to 64 feet) specified by builders. The joists may be slightly heavier than some fabricated joists currently on the market, but tests have shown the lodgepole pine joists have significantly superior mechanical properties—that is, the lodgepole pine joists warrant design values for stiffness and resistive moment that are significantly greater than competitive fabricated joists of comparable depth and price.

The edge-glued lumber panels are designed for sound-knotted grades of mill work. They will be produced by doweling, center ripping, kiln drying, and then moulding small-diameter lodgepole pine stem sections into trapezoidal shapes that will be edge-glued into panels 100 inches long by 48 inches wide. The sanded panels will be available in a range of thicknesses (1 to 3 inches) for use in mill work such as tabletops, doors, windows, stair treads, and wall panels. They may also find use as truck flooring.

The three products just described will provide 90 percent of plant revenues. The remaining 10 percent will come from production of small roundwood products (tree props and fence rails), studs, pulp chips, and particleboard furnish.

Raw Material Availability

The facility is designed to use the enormous—and presently unmerchantable—volumes of small-diameter lodgepole pine timber available from stagnant and overstocked stands in northwestern Montana.

Currently, little of this material is being used by industry, and available quantities greatly exceed the volumes required by the proposed plant. That is, over the 22-year life of the project the proposed plant would consume about half the tonnage available in the procurement area of sub-sawlog-size, marginal sawlog, and dead lodgepole pine timber.

Cash-Flow: 50 Percent Debt, 50 Percent Equity Financing

The financial analysis is based on the assumption that the project will be developed by a Fortune-500-type company, domestic or foreign, with a good credit rating and ready access to the financial markets. To summarize, a line of credit would be established (interest rate assumed to be 10 percent annually) to handle construction activities and to provide working capital for the initial phases of plant operation. Long-term financing for the facility will consist of a $31 million bond issue at 10 percent interest, and a $31 million common stock issue.

Average annual return on the equity investment of $31 million is estimated at 25.1 percent after corporate income taxes—over the 22-year life of the project.

Cash-Flow: Excluding Financing Flows

Because the return on investment varies as the project's financing varies, an additional analysis was performed calculating the return independently from the specific financing approach. This analysis estimated the average annual rate of return to all investors at 16.8 percent after corporate income taxes—over the 22-year life of the project.

FOREWORD

The Northern Region supports the efforts of Dr. Peter Koch and associates who worked in cooperation with the Intermountain Research Station, Montana Science and Technology Alliance, and the University of Montana for the development of a possible solution toward putting under management stands of stagnated lodgepole pine and the utilization of subsawtimber size and dead timber.

The primary source of timber for the proposed facility is the Kootenai and other National Forest areas within a 75-mile radius of Libby or Troy.

The facility will require 200,000 tons (ovendry basis) annually of subsawtimber size, dead, and marginal sawlogs. Most of the subsawtimber and dead sawlogs will be lodgepole pine.

The specific source of raw material will be through management of subsawtimber size lodgepole pine stands and the purchase of dead and marginal sawtimber directly from forest managers or from other purchasers. The acquisition of subsawtimber size lodgepole pine will be through commercial timber sales or service contracts with salvage rights, depending on the costs of treatment compared to the revenues derived.

The acreage to be harvested could range up to 2,500 acres annually. The resource data from the Kootenai National Forest, based on the final Forest Plan, are as follows:

1. Suitable timber base is 1,263,000 acres.

2. First decade allowable sale quantity (regulated) is 202 million board feet or 50.5 million cubic feet annually. Achieving the offering of the ASQ is dependent on funding levels received by the Forest and the ability to fully implement the provisions of the Forest Plan.

3. First decade programmed sell level (regulated plus unregulated) is 227 million board feet annually.

4. Conversion of 32,000 acres of stagnated lodgepole pine stands by the fifth decade.

There are additional resources in the Tally Lake District of the Flathead National Forest. These include approximately 20,000 acres of subsawtimber size lodgepole pine. Currently, most of it is unroaded. However, capital investment road funds are planned to access these areas.

The Region and National Forests involved, particularly the Kootenai, will make a reasonable attempt to make available the timber resource necessary to meet the anticipated needs of the proposed facility. Kootenai personnel believe the raw material exists to equal the needs of the operation for over a 10-year period, and most likely a 20-year period, if it is possible to economically utilize lodgepole pine (including stagnant, marginal sawtimber, dead sawtimber, and some green sawtimber) on slopes that may exceed 55 percent and at haul distance up to 75 miles while meeting the environmental requirements of the Forest Plan. In addition, competition for available resources is present and expected to increase. Existing industries will potentially compete more heavily in the future. Competition for subsawtimber size material will increase due to the new paper mill at Usk, WA, and the expected reductions in chip production at existing sawmills due to lower available timber supplies in the State of Montana.

We believe this proposal can be an important tool in achieving the desirable goal of putting extensive stands of stagnated lodgepole pine in northwestern Montana under management.

Christopher Risbrudt

for John W. Mumma
Regional Forester
Northern Region
Forest Service

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CHAPTER 1: INTRODUCTION

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This paper explores the technical and economic feasibility of establishing in northwestern Montana an integrated manufacturing plant designed to solve a land management problem on acreages growing lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), while simultaneously providing employment for significant numbers of Montana residents and providing an appropriate return for entrepreneurs on the multimillion dollar investment required. The proposed enterprise will harvest an extensive acreage of lodgepole pine annually and operate a major center for segmenting whole trees into components to maximize value. Products include tree props, fabricated joists, edge-glued lumber panels, and oriented-strand board (OSB)—a type of structural flakeboard. Most of the projected output will be marketed outside the State of Montana.

A single-product plant manufacturing structural flakeboard from lodgepole pine in Montana—while much simpler than a multiproduct plant—would appear to be uncompetitive for three reasons. First, the freight costs to West Coast, Southwest, and Midwest markets are significantly higher than those from locations closer to these markets. Second, the magnitude of the available wood resource, in stem sections 5 inches in diameter and larger, is such that a stand-alone flakeboard plant would be limited to perhaps 150 million ft^2 annually ($^3/_8$-inch basis); manufacturing costs, exclusive of wood costs, for such a small plant are significantly higher than those of much larger plants already in operation. Finally, harvesting costs of sub-sawlog-size lodgepole pine (the resource that is available in quantity) growing on Montana's steep terrain are probably higher than those for some other tree species on gentler ground.

The unusually good mechanical properties of roundwood from sub-sawlog-size lodgepole pines in Montana, however, offer the possibility of a multiplicity of products sufficiently high in average value to overcome the previously mentioned economic disadvantages. An integrated plant converting 67 percent of entire tree stemwood into a spectrum of such products appears to be viable; the products proposed (exclusive of pulp chips and other residues) have a net plant-gate value of $183 to $543 per ovendry ton of wood content, with average value of $285. Residues from the plant include some pulp chips, but most of the residue tonnage will be hog fuel burned for process heat required by the operation.

1-1 GENERAL DESCRIPTION OF THE MONTANA LODGEPOLE PINE SITUATION

Although most acreages dominated by lodgepole pine are solidly forested in lodgepole pine, some contain significant components of western larch (*Larix occidentalis* Nutt.), Douglas-fir (*Pseudotsuga menziesii* var. glauca [Beissn.] Franco), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), or bigtooth aspen (*Populus grandidentata* Michx.). Growth potential in Montana varies from only slightly more than 20 ft^3 per acre per year to more than 100 ft^3 per acre per year. Annual precipitation varies from a low of slightly less than 20 inches to a maximum of near 40 inches. Terrain varies from nearly level to mostly steep; in aggregate, perhaps two-thirds of the lodgepole pine acreage is on slopes of less than 45 percent. A few of the acreages are stony and boulder strewn, but most are not excessively rocky. Mortality—primarily from mountain pine beetle attacks—varies from the preponderance of stems to virtually none of the stems. Defects in live trees that adversely affect utilization in solid wood products include porcupine scars (in some areas occurring on three-quarters of the stems and at several heights in each stem), stem crook, stem sweep, stem fork, cankers, fire scars, frost cracks, pith eccentricity and excessive compression wood content, excessive spiral grain, excessive taper, and excessive limbiness. Degree of defect varies greatly among and within acreages.

Accessibility of the lodgepole acreages also varies significantly. Most have roads to their perimeters, and many have some interior roads; but a few can be reached only on foot. All are within 50 miles of a railhead.

In virtually all of the acreages, stand type varies in a continuum. Classes of stands include "dog-hair" stands of trees less than 3 inches in d.b.h., pole stands with all trees live, pole stands with many dead trees, pole stands with dense understories of smaller trees, stands of sparsely stocked small sawtimber—usually over 200 years old, vigorous stands of large pole timber (that is, 6 or 7 inches in d.b.h.), stands of dead trees killed by bark beetles—many of suitable size for cabin logs, and stands of a variety of ages and generally low stocking containing relicts of past insect attacks as well as a range of smaller trees—usually suffering from mistletoe attack and cankers of various descriptions.

The preponderance of lodgepole cubic volume in Montana is found in trees less than 8 inches in d.b.h.—that is, in trees generally too small to yield sawlogs. Trees are typically about 60 to 100 years old, with few stands less than 40 years old and some over 200 years old.

Lodgepole pine stand types that have particular significance to the study can be described as sub-sawlog-size **stagnant** (fig. 1-1), **marginal sawlog** (fig. 1-2), and **dead sawtimber** (fig. 1-3).

Figure 1-1—Sub-sawlog-size stagnant stand of lodgepole pine at 4,200 feet in the Zulu Creek-Smoot Creek area of the Kootenai National Forest in Montana. The labeled trees measure 3$^1/_2$ to 4 inches in d.b.h.

Figure 1-2—Marginal sawlog stand of lodgepole pine looking south from the Middle Fork of Cottonwood Creek at 5,500 feet on the Deerlodge National Forest in Montana.

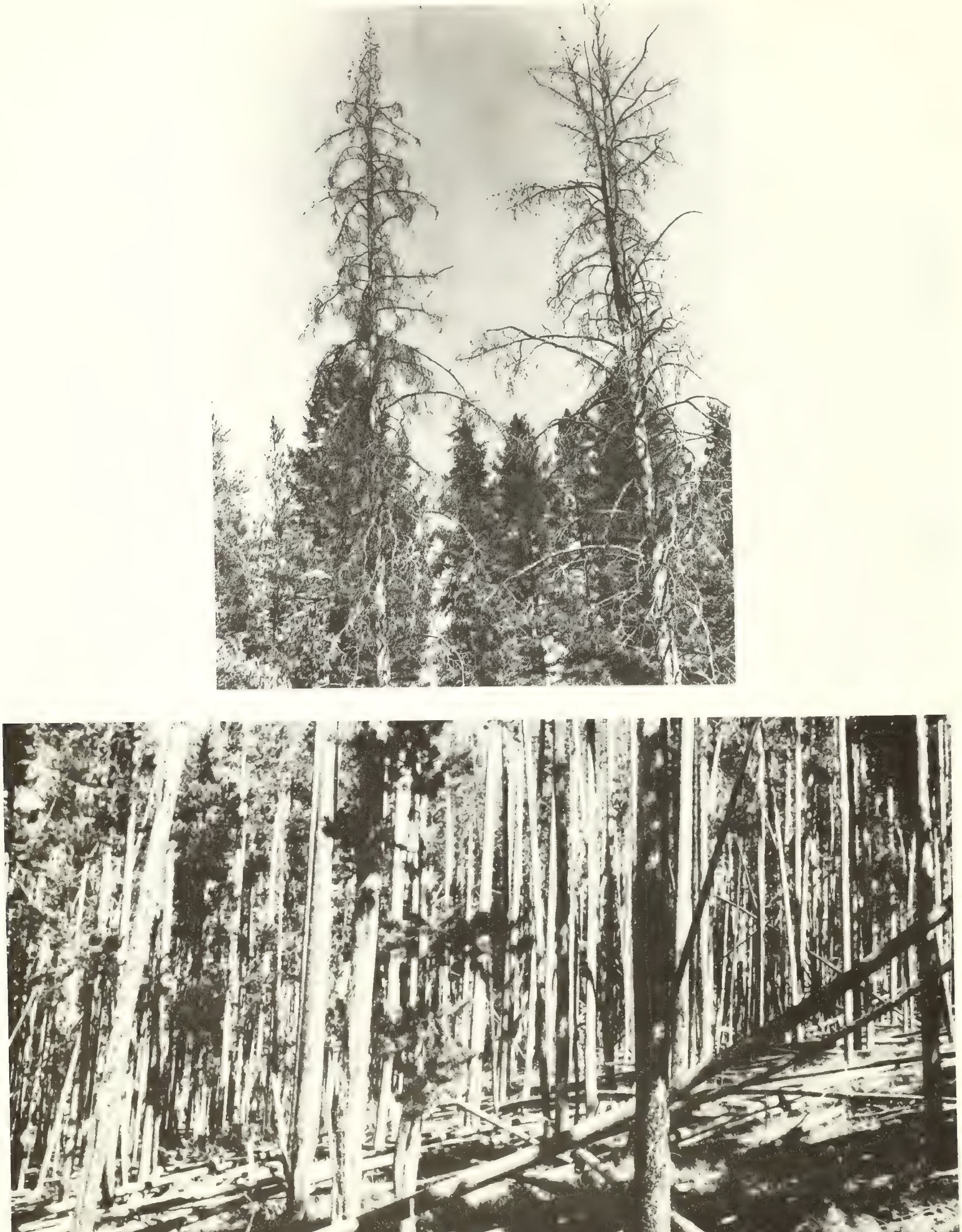

Figure 1-3—A stand of dead lodgepole pine sawtimber in Montana. The trees were killed by mountain pine beetles.

In the d.b.h. class from $3^{1}/2$ to 4 inches, trees are generally about 38 feet tall, with few shorter than 25 feet and few taller than 55 feet; stemwood-average specific gravity of such trees ranges from 0.36 to 0.52, but is generally about 0.43 (based on ovendry weight and green volume). In trees $3^{1}/2$ to 4 inches in diameter, crown ratios are mostly in the range from 25 to 70 percent, with average near 45 percent. Below-crown stem taper (inside bark) is generally more than 0.4 and less than 0.8 inch per 100 inches, and averages about 0.6 inch. Within-crown stem taper (inside bark) averages about 1.3 inches per 100 inches.

Data from Montana lodgepole stands selected for 1985 thinning studies suggest that an average unthinned acre might contain 1,360 live stems 3 inches in d.b.h. and larger, totaling 3,400 ft^3 of stemwood, or about 43 tons of stemwood (ovendry basis). Considering all Montana lodgepole stands, however, a more conservative estimate might be 1,000 live stems per acre measuring 3 inches in d.b.h. and larger, totaling 2,500 ft^3 of stemwood, or about 31 tons of stemwood, ovendry. Even this lower estimate may prove too high on some lodgepole pine acreages in Montana.

1-2 CURRENT STUMPAGE VALUES VS. COST OF SELLING THE STUMPAGE

In discussing the stumpage value of lodgepole pine in Montana, it is necessary to differentiate the stands by d.b.h.

In northwestern Montana, sawtimber stands comprised mostly (80 percent or more) of live trees 9 inches in d.b.h. and larger typically have a stumpage value (1988) of about \$60 to \$80 per thousand board feet (M bd ft) Scribner scale, with sale size ranging from a few acres up to 1,000 acres. When clearcut, such stands may yield 10 to 12 M bd ft per acre based on Scribner log scale.

The sawtimber-size, mostly live lodgepole pine just described is not the subject of this analysis, however. Our concern is with the extensive sub-sawlog-size stagnant, marginal sawlog, and dead-timber stands. In most areas where such problem stands of lodgepole pine grow in Montana, post and pole operators nibble away at them, each cutting 1 to 3 acres annually in close proximity to existing roads; such post and pole operations are sometimes used to achieve cosmetic thinning along these roads. These operators generally pay a stumpage fee of \$5 to \$7 per thousand lineal feet of product.

In the problem stands, firewood stumpage values sometimes exceed stumpage values for other uses. Dead-timber stumpage is frequently sold for \$1 per M bd ft Scribner scale.

Occasionally, a sawlog sale of 15 to 500 acres is made in these problem stands, but virtually always at a stumpage cost less than that required to prepare the sale. Stumpage fees usually are in the \$6 to \$20 range, with some sales made at \$1 per M bd ft (Scribner log scale), and few as high as \$25.

Costs of preparing and executing a small-acreage, low-volume sawlog sale, exclusive of road construction costs, vary greatly among ownerships and also depend on the characteristics of the sale area. Sale costs per M bd ft of sawlogs are inversely related to sale acreage and to timber volume sold per acre. Sales on the areas studied usually encompass less than 40 acres, with lodgepole pine sawlog volume generally less than 8,000 bd ft per acre.

The direct costs to Forest Service Ranger Districts (or equivalent on State or Bureau of Land Management forests) were reported as low as \$2 in one area, but more typically are \$12 to \$25 per M bd ft, Scribner scale. When all appropriate direct and indirect costs within Ranger Districts, Supervisors' Offices, and Regional Headquarters are included, however, total sales costs per M bd ft of lodgepole pine sold in small tracts appear to be in the range from \$40 to \$60, with one National Forest reporting total costs of \$85. Such costs include not only those incurred by technicians, timber sales officers, and road planning engineers, but also those incurred by specialists in silviculture, wildlife habitat, landscape esthetics, watershed quality, archeology, and law (together with all supporting staff in Supervisors' Offices and Regional Headquarters).

Volumes of forest residues resulting from sawlog sales in problem lodgepole pine stands are generally great because most of the sawlog operators have no profitable outlet for sub-sawlog-size stems.

1-3 MANAGEMENT OBJECTIVES AND SILVICULTURAL CONSIDERATIONS

With virtually no exceptions, the land managers have concluded that thinning more-or-less stagnated stands that are 70 to 100 years old is an uneconomic procedure; this is so because products recovered in such thinning have low value, growth response is not outstanding, and thinning cost is great.

With almost no exceptions, the land managers are seeking some methodology to replace stagnated and unmarketable stands of lodgepole pine with new vigorous stands of the same species—and they want to do this without expending significant amounts of money. They visualize that this must be done by phased clearcutting and natural regeneration, but they have very few stumpage purchasers willing to build the necessary temporary roads, clear-fell all diameter classes of all species, and leave the acreage with no more than 25 tons (ovendry) of slash per acre and with sufficient seed distributed on exposed mineral soil to ensure natural regeneration (fig. 1-4). When the managers contract such stand replacement operations, they incur costs of \$200 to \$700 per acre—costs that they find hard to economically justify. Most of the managers do not find it necesary to plant such clearcut areas if the seedbed is properly prepared with mineral soil adequately exposed and if viable seeds are available from serotinous cones on the ground or from adjacent trees bearing open cones.

Assuming that stand replacement can be accomplished with little or no expenditures, most of the managers think that they can internally fund thinning of the regenerated stands when the trees are 15 to 20 feet tall. Cost of such

Figure 1-4—Lodgepole pine clearcut with a steep-slope feller buncher. Small stems were crushed. All slash was left on the ground unpiled and unburned. Regeneration will be natural. The access road is temporary.

precommercial thinning is usually $60 to $85 per acre, but may be as high as $300 per acre if vegetation is dense in high-rainfall areas.

In virtually all cases, the managers must give great consideration to improvement of wildlife habitat, protection of stream quality, and protection of esthetic values—but these considerations are not generally seen as prohibiting planned stand replacement as long as clearcuts do not exceed 40 acres, are spaced to maintain elk or deer hiding cover, do not disturb streams, and are located and contoured to be visually acceptable.

While prescribed burning or wildfire might appear to offer a solution on some acreages, few managers are willing to embrace the idea of deliberately wasting the enormous tonnages of wood that would be consumed by such fires. And such fires would offer limited opportunity for protecting stream quality, wildlife habitat, and esthetic quality of the forest.

1-4 SUMMARY OF THE PROBLEM

In brief, land managers face the problem of how to clearcut and regenerate large acreages of stagnated or otherwise unproductive stands of lodgepole pine without large expenditures of funds to cover the direct costs. Additionally, managers must accomplish this stand replacement according to a management plan without jeopardizing the other values of the forest—that is, wildlife habitat, stream quality, and esthetic quality. Silviculturally, the goal is to replace these stagnant stands, with vigorous new stands that will be thinned to a prescribed stocking density when the new trees attain a height of about 15 to 20 feet. Additionally, harvesting the stagnant stands should yield a positive contribution to the economy—as contrasted to waste through destruction by fire, or by insects and disease.

Finally, the industrial manager of the proposed operation—who harvests, prepares the site, and utilizes the trees—must make an appropriate profit on the investment in harvesting, transport, and conversion facilities. This return, after taxes, should be at least 15 percent annually on the entire investment, assuming no funds have been borrowed.

CHAPTER 2: RESOURCE DATA, TERRAIN EVALUATION, PLANT SITE SELECTION, AND HARVESTING PROCEDURES

CONTENTS

2-1 MONTANA TIMBER RESOURCE DATA

Some 20.2 million acres, roughly 22 percent of the State of Montana, are covered with forest. Nearly three-fourths of Montana's forest land is publicly owned—most under administration of Federal agencies. The Forest Service has the most; its 13.8 million acres is 68 percent of the total and 93 percent of the publicly administered forest land, as follows (Green and others 1985):

Owner group	**Area**	**Percent of total**
	Thousand acres	
Public		
Forest Service	13,817.2	68
Other public	1,053.4	6
Total	14,870.6	74
Private	5,355.4	26
Total	20,226.0	100

Nearly 16 million acres are classed as productive timberland. Green and others (1985) estimated Montana's area of productive forest land **available** for growing and harvesting industrial wood products—the **commercial timberland** base—to be 13.6 million acres. The same general ownership pattern evident in the total forest land holds for the forest land classed as commercial timberland. Sixty-six percent is under public administration, mostly Federal. Of the remainder under private ownerships (34 percent), about one-third is owned by forest industries and about two-thirds is owned by farmers or ranchers (Green and others 1985).

Ownership class	**Montana's commercial forest area**	**Percent of total**
	Thousand acres	
National Forest	8,161.8	60
Other public	759.3	6
Forest industry	1,601.3	12
Farmers and other private	3,048.9	22
Total	13,571.3	100

Forests in Montana contain 27 species of trees—17 conifers and 10 hardwoods. How and where they grow depends on such things as elevation, available moisture, and soil characteristics. As a general rule, where there are mountains there are forests. The larger, wide, low-elevation valleys generally are not forested except for hardwoods growing along the streams.

The most heavily forested area of Montana is west of the Continental Divide (fig. 2-1) where the high mountain ranges trigger the release of large amounts of moisture from westerly airflows coming from the Pacific Ocean. There the nature of the forest changes quite noticeably over relatively short distances because the habitat conditions change rather rapidly with respect to elevation and moisture. East of the Divide the climate is much drier than west of the Divide. Consequently, the eastern Montana forests are restricted to higher elevations and exist in scattered patches (Green and others 1985).

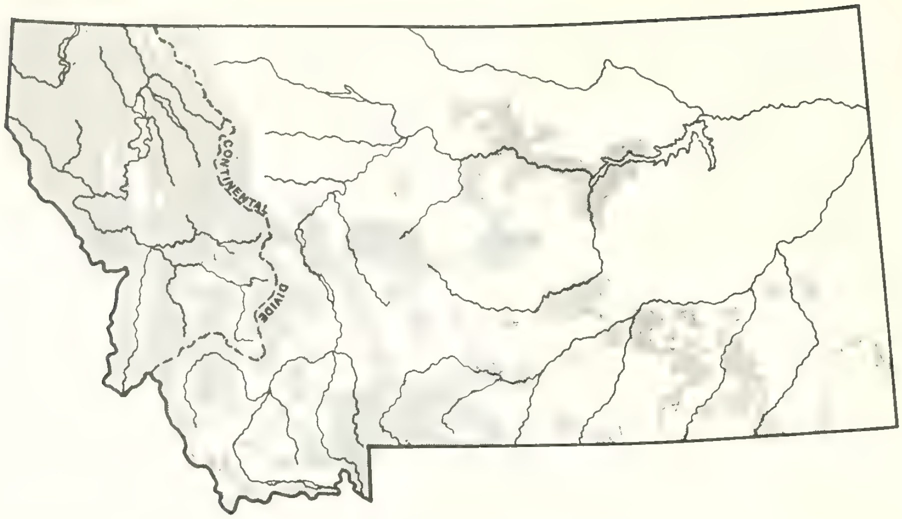

Figure 2-1—Forested areas in Montana—depicted by shading. (Drawing after Green and others 1985.)

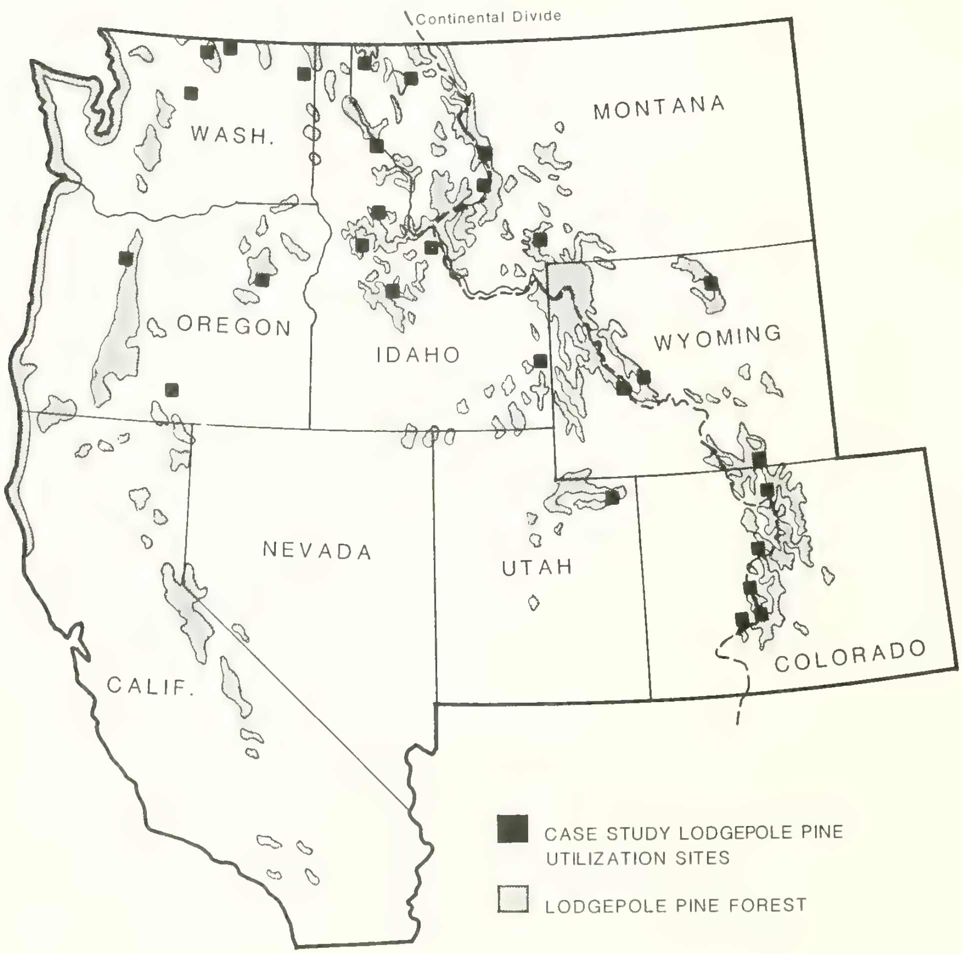

Figure 2-2—Distribution of lodgepole-pine-dominated forests in the United States. The black squares denote some typical lodgepole pine acreages on which the managers wish to improve values through stand replacement.

As explained in the introduction to this analysis, the proposed enterprise is principally concerned with only one of the 27 species of timber trees found in the State—lodgepole pine.

2-2 MONTANA LODGEPOLE PINE RESOURCE DATA

Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) is dominant on about 13 million acres of commercial forest land in the United States (fig. 2-2) containing 26.4 billion ft^3 of lodgepole **growing stock** and more than 71 billion bd ft of lodgepole sawtimber, mostly in Montana, Idaho, Wyoming, Colorado, and Oregon. Montana accounts for nearly half the volume of the species growing in the Rocky Mountains.

In Montana, lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) dominates on about 3.9 million acres of the State's 13.6 million acres of commercial forest land, with about 8.4 billion ft^3 of lodgepole pine growing stock and 18.7 billion bd ft of sawtimber (table 2-1). Approximately 33 percent of the softwood growing stock and 21 percent of the softwood sawtimber in the State is lodgepole pine (Green and others 1985).

Approximately 64 percent of the dry weight of needle-free above-ground biomass of lodgepole pine trees in Montana is in trees smaller than the 10-inch d.b.h. class (table 2-2).

Counties west of the Continental Divide have more lodgepole pine volume than those east of the Divide; greatest volumes of lodgepole **growing stock** (that is, stemwood volume from a 1-foot-high stump to a top diameter outside bark of 4 inches in all trees 5.0 inches in d.b.h. and larger) are found in Lincoln, Beaverhead, and Flathead Counties (fig. 2-3 and table 2-3). Concentration of growing-stock volume is greatest in Lincoln County.

Table 2-1—Net volume of lodgepole pine growing stock and sawtimber in Montana by ownership class, and acreage dominated by lodgepole, 1980 (Green and others 1985)

Ownership class	Growing stock[1]	Sawtimber[2]	Lodgepole-dominated commercial forest area
	Million ft^3	*Million bd ft, International 1/4-inch scale*	*Thousand acres*
National Forest	6,660.6	15,094.1	3,100.0
Other public	280.9	634.3	114.3
Forest industry	641.4	1,098.3	306.7
Farmers and other private	787.5	1,842.2	344.5
Total	8,370.4	18,668.9	3,865.5

[1]Growing stock is comprised of all trees 5 inches in d.b.h. and larger; the volume is for stemwood only from a 1-foot stump height to a 4-inch diameter top measured outside bark.

[2]Sawtimber is defined as trees 9 inches in d.b.h. and larger; the volume is for stemwood from a 1-foot stump height to a 7-inch top diameter measured outside bark.

Table 2-2—Dry weight of lodgepole pine trees, by tree component and diameter class—Montana (Van Hooser and Chojnacky 1983)

D.b.h. class	Bole[1]	Top[1]	Total
Inches	*- - - - - - Thousand tons, ovendry basis - - - - - -*		
[2]2	0	6,509	6,509
[2]4	0	21,301	21,301
6	30,654	16,883	47,537
8	35,351	9,120	44,471
10	25,842	6,248	32,090
12	15,864	3,893	19,757
14	7,485	1,669	9,154
16	3,129	637	3,766
18	1,123	225	1,348
20+	795	154	949
Total	120,243	66,639	186,882

[1]Trees 5 inches and larger in d.b.h.: Bole weight = ovendry weight of wood and bark from a 1-foot stump height to a 4-inch top diameter, outside bark. Top weight = ovendry weight of wood and bark from a 4-inch diameter (inside bark) to apical tip, plus branch material down to 1/4-inch diameter.

[2]Trees less than 5 inches in d.b.h.: Total ovendry weight of wood and bark from a 1-foot stump height to the apical tip, plus branch material down to 1/4-inch diameter (tabulated under "Top").

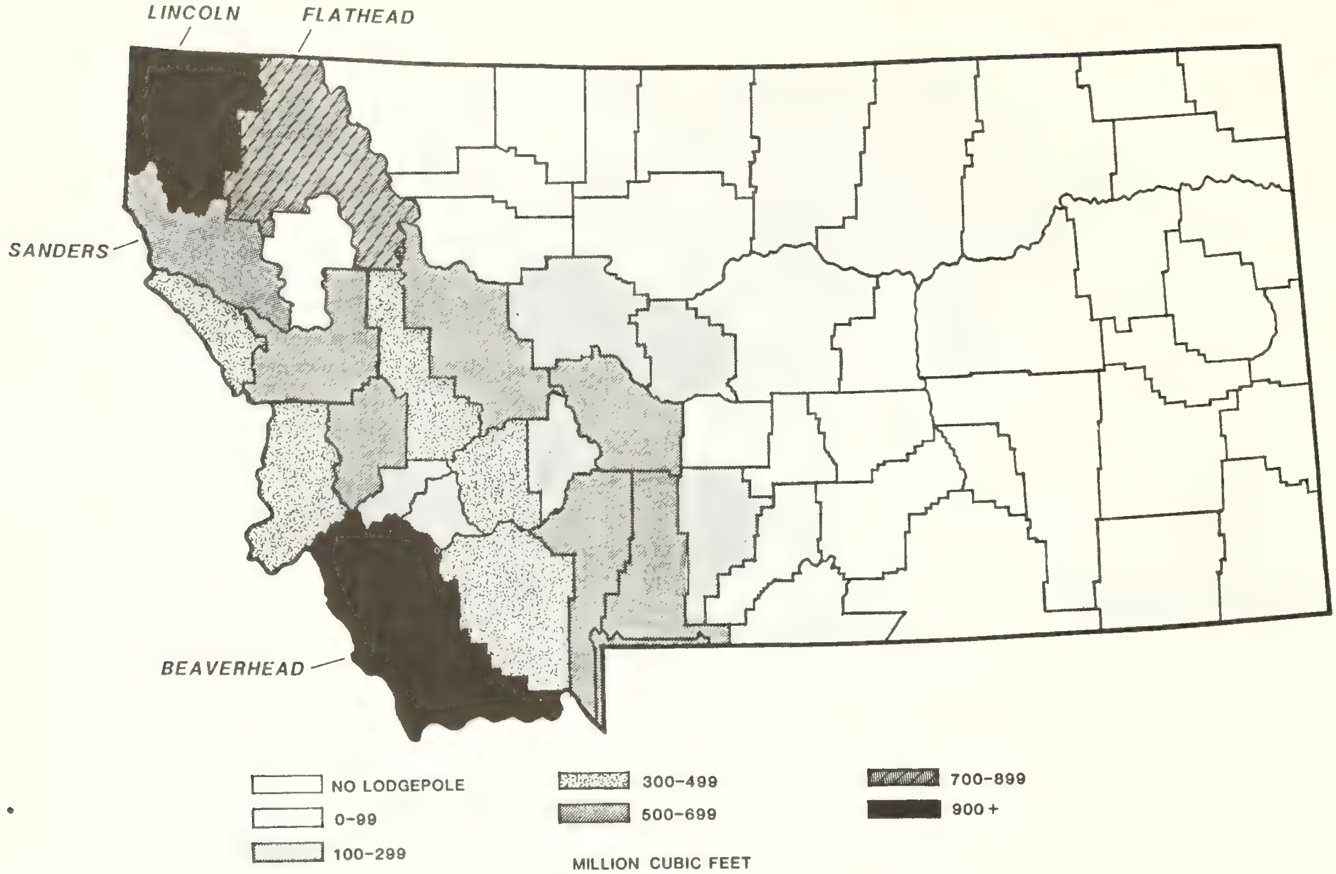

Figure 2-3—Distribution of lodgepole pine volume in Montana counties. Volume data (million cubic feet) are for stemwood in growing stock (trees 5 inches in d.b.h. and larger) from a 1-foot-high stump to a 4-inch top diameter measured outside bark. (Data from the Forest Survey Research Unit, Intermountain Research Station, Ogden, UT.)

Table 2-3—Volume[1] of lodgepole pine growing stock, by Montana county, on commercial timberland administered by the Forest Service in the National Forest System, and administered by others (the State of Montana and other public agencies, industry, and private owners)

County	Forest Service	Other	Total
	Thousand ft³		
Beaverhead	895,522.4	47,504.9	943,027.3
Big Horn	0	0	0
Blaine	0	2,999.3	2,999.3
Broadwater	109,575.0	5,182.6	114,757.6
Carbon	36,376.9	2,054.5	38,431.4
Carter	10,028.3	0	10,028.3
Cascade	163,874.5	28,640.4	192,514.9
Choteau	18,744.7	7,081.1	25,825.8
Custer	0	0	0
Daniels	0	0	0
Dawson	0	0	0
Deer Lodge	110,024.6	56,456.6	166,481.2
Fallon	0	0	0
Fergus	83,916.9	13,838.1	97,755.0
Flathead	474,689.0	248,676.5	723,365.5
Gallatin	472,255.1	96,054.7	568,309.8
Garfield	0	4,241.3	4,241.3
Glacier	12,658.9	1,980.0	14,638.9
Golden Valley	16,153.5	1,206.2	17,359.7
Granite	585,048.7	68,759.6	653,808.3
Hill	0	1,530.7	1,530.7
Jefferson	393,684.9	11,042.9	404,727.8
Judith Basin	255,524.3	1,712.0	257,236.3
Lake	49,912.5	45,409.9	95,322.4
Lewis and Clark	510,186.9	61,763.6	571,950.5
Liberty	0	816.6	816.6
Lincoln	999,922.8	185,793.9	1,185,716.7
McCone	0	0	0
Madison	389,018.2	84,998.9	474,017.1
Meagher	419,481.8	95,262.1	514,743.9
Mineral	393,425.6	42,663.2	436,088.8
Missoula	310,344.0	242,655.3	552,999.3
Musselshell	0	0	0
Park	485,074.7	63,766.7	548,841.4
Petroleum	0	0	0
Phillips	0	1,732.5	1,732.5
Pondera	63,907.8	1,364.0	65,271.8
Powder River	16,630.6	0	16,630.6
Powell	316,508.9	134,730.6	451,239.5
Prairie	0	0	0
Ravalli	319,556.5	12,225.8	331,782.3
Richland	0	0	0
Roosevelt	0	0	0
Rosebud	3,337.4	0	3,337.4
Sanders	550,969.4	91,837.0	642,806.4
Sheridan	0	0	0
Silver Bow	169,722.1	32,507.1	202,229.2
Stillwater	21,131.0	1,566.6	22,697.6
Sweet Grass	133,697.0	6,613.6	140,310.6
Teton	90,778.5	3,188.5	93,967.0
Tooele	0	0	0
Treasure	0	0	0
Valley	0	56.5	56.5
Wheatland	32,473.7	1,333.7	33,807.4
Wibaux	0	0	0
Yellowstone	0	0	0

[1]Stemwood in live lodgepole pine trees 5 inches in d.b.h. and larger from a 1-foot-high stump to a 4-inch top diameter measured outside bark. Data, based on survey information collected from 1966 through 1980, are from a special tabulation compiled by the Forest Survey Research Work Unit, Intermountain Research Station, Ogden, UT.

Numbers of lodgepole pine trees, by diameter class, in each Montana county where lodgepole pine is found—together with stemwood cubic volume in growing stock—are tabulated in appendix I. As previously noted, and as shown by appendix I, numbers of trees and stemwood volumes in growing stock are greatest on land administered by the National Forest System. Study of figure 2-3 and appendix I, together with extended conversations with resource analysts of the Forest Service's Intermountain Research Station, and with managers of lodgepole pine lands administered by the National Forest System, strongly suggest that the greatest concentration of available lodgepole pine in sub-sawlog and marginal sawlog size classes is in Lincoln County, together with adjoining northern Sanders County and western Flathead County.

2-3 LODGEPOLE PINE RESOURCE IN LINCOLN, FLATHEAD, AND SANDERS COUNTIES

A plant centrally located in Lincoln County might draw lodgepole pine from throughout the county plus western Flathead County and northern Sanders County (fig. 2-3). The lodgepole pine resource in these three counties can be assessed in terms of acreages, numbers of trees, and stemwood cubic volume or weight.

Acreage on Which Lodgepole Pine Predominates

Of the 3.9 million acres in Montana's commercial timberlands on which lodgepole pine dominates, about one-third (1.3 million acres) are in Lincoln, Flathead, and Sanders Counties.

Acreage of lodgepole pine forest type within the commercial timberlands of Flathead, Lincoln, and Sanders Counties can be classified according to ownership. Most is administered by the National Forest System, but a significant proportion of the lodgepole pine forest type within these three counties has other ownerships, as follows (data from a special tabulation compiled from 1977 information by the Forest Survey Research Unit, Intermountain Research Station, Ogden, UT):

Ownership status	Acres	Proportion of non-National Forest ownerships
		- - Percent - -
Other public (not National Forest)	46,759	17.3
Forest industries	164,437	61.0
Farmer and other private	58,600	21.7
Total	269,796	100.0

County acreage within the National Forests of commercial timberlands in lodgepole pine type cannot be readily derived from available survey data. It can be approximated, however, by utilizing the data in table 2-7 (see p. 14) to conclude that in the three-county area, 79.4 percent of the lodgepole pine volume is on lands administered by the National Forests and 20.6 percent is on lands administered by other owners as defined in the preceding tabulation.

From these proportions it can be inferred that National Forest area of lodgepole pine type classified as commercial timberland totals about 1,039,893 acres within the three-county area. These data suggest that, with all ownerships considered, lodgepole pine dominates on 1,309,689 acres of the commercial timberland in the three-county area.

Numbers of Lodgepole Pine Trees

It is useful to know something about the numbers of lodgepole pine trees growing in the three counties and their distribution by diameter class. Excluding the 2-inch class (1.0 to 2.9 inches), which seems too small for utilization, the 4- through 6-inch diameter classes (that is, trees 3.0 through 6.9 inches in d.b.h.) comprise close to three-quarters of the remaining stems, as follows (table 2-4):

County	Total stems in the 4- through 30-inch diameter classes	Stems in the 4- through 6-inch diameter classes	
	Number	*Number*	*Percent*
Flathead	183,157,517	139,711,604	76.3
Lincoln	265,196,954	193,180,112	72.8
Sanders	125,913,469	86,986,929	69.1

With the 2-inch class (1.0 through 2.9 inches in d.b.h.) excluded, trees 8.9 inches in d.b.h. and smaller comprise 90 percent of all remaining lodgepole stems in these three counties (table 2-4).

While not specific to lodgepole pines from Lincoln, Flathead, and Sanders Counties, the data in table 2-5 are useful in visualizing the dimensions and weights of trees 3, 6, and 9 inches in d.b.h. These data represent average values for all lodgepole pines (var. *latifolia*) in North America. The weights of all above-stump tree portions (including foliage) averaged as follows (Koch 1987):

D.b.h.	Average weight of all tree parts above 6-inch-high stump: Green	Ovendry
Inches	*- - - - - Pounds - - - - -*	
3	54	28
6	334	171
9	875	453

In such trees 3, 6, and 9 inches in d.b.h., stemwood from 6-inch-high stump to apical tip represents 72 to 77 percent of the aboveground tree weight, stembark 7 to 11 percent, foliage-free branches 7 to 10 percent, and foliage and cones 8 to 11 percent (table 2-6).

Table 2-4—Number of live lodgepole pine trees on commercial timberland in three Montana counties, by diameter class[1] and administrative class

Diameter class	National Forests	Other[2]	Total
Inches	*Number of trees*		
Flathead County			
2	35,721,959	33,126,047	68,848,006
4	52,731,730	34,974,566	87,706,296
6	34,475,806	17,529,502	52,005,308
8	18,455,405	7,997,966	26,453,371
10	7,031,519	3,260,056	10,291,575
12	3,133,559	1,011,455	4,145,014
14	1,402,830	442,101	1,844,931
16	467,798	71,333	539,131
18	127,204	12,343	139,547
20	20,018	5,014	25,032
22	4,783	864	5,647
24	256	1,409	1,665
Total	153,572,867	98,432,656	252,005,523
Lincoln County			
2	32,920,429	27,745,757	60,666,186
4	78,215,244	28,002,686	106,217,930
6	72,408,716	14,553,466	86,962,182
8	38,097,171	6,211,449	44,308,620
10	15,899,375	2,294,163	18,193,538
12	6,060,588	602,682	6,663,270
14	1,765,928	269,305	2,035,233
16	523,057	48,443	571,500
18	149,023	11,328	160,351
20	64,104	3,109	67,213
22	15,732	943	16,675
24	0	432	432
26	0	0	0
28	10	0	10
Total	246,119,377	79,743,763	325,863,140
Sanders County			
2	15,931,695	4,911,418	20,843,113
4	38,800,363	3,596,967	42,397,330
6	39,815,018	4,774,581	44,589,599
8	20,755,188	3,404,108	24,159,296
10	8,277,911	1,170,727	9,448,638
12	3,294,347	453,438	3,747,785
14	927,548	165,489	1,093,037
16	310,115	40,462	350,577
18	67,109	6,463	73,572
20	25,136	14,384	39,520
22	7,253	3,939	11,192
24	2,923	0	2,923
Total	128,214,606	18,541,976	146,756,582

[1]Diameter classes (measured at breast height, outside bark) span 1.9 inches; for example, the 4-inch class spans from 3.0 to 4.9 inches. Data, based on survey information collected from 1966 to 1980, are from a special tabulation compiled by the Forest Survey Research Unit, Intermountain Research Station, Ogden, UT.
[2]State and other public, forest industry, and private ownerships.

Table 2-5—Some useful average dimensions and weights of lodgepole pine trees (var. *latifolia*) of three diameters[1]

Property	Tree d.b.h., inches 3	6	9
Height to 1-inch diameter outside bark, feet	26.3	48.2	60.0
Height to 2-inch diameter inside bark, feet	16.5	39.1	52.9
Height to base of live crown, feet	16.5	28.9	35.6
Diameter inside bark at base of crown, inches	2.0	3.9	5.8
Average branch diameter (near stem), inch	.35	.51	.75
Stemwood data; stump top to apical tip			
Volume, ft^3	.75	4.95	13.33
Ovendry weight, lb	20.2	130.4	339.7
Ovendry weight /ft^3 of green volume, lb	26.9	26.3	25.5
Stemwood volume within live crown, percent of total stemwood volume to apical tip		26.5	
Stemwood taper inside bark, inches/100 inches			
From 6-inch-stump to live-crown base	.63	.78	1.05
From base of crown to apical tip	1.31	1.59	1.85

[1]These data, summarized from Koch (1987), are averages for trees 3, 6, and 9 inches in d.b.h. collected throughout the major range of var. *latifolia* in North America; that is, from 40 to 60 degrees latitude.

Table 2-6—Average weight proportions of aboveground tree components of lodgepole pine (var. *latifolia*) of three diameters, from 6-inch-high stump level to apical tip[1]

Tree component and moisture basis	Tree d.b.h., inches 3	6	9
	Percent		
Stemwood			
Green	71.7	76.9	76.3
Ovendry	72.6	76.3	75.1
Stembark			
Green	11.0	7.8	6.5
Ovendry	10.1	7.8	6.8
Dead branches			
Green	1.3	1.4	1.5
Ovendry	2.1	2.1	2.4
Live branches (wood + bark)			
Green	5.4	6.0	8.0
Ovendry	5.3	6.0	7.9
Foliage and cones			
Green	10.6	7.9	7.7
Ovendry	9.9	7.8	7.8
Total			
Green	100.0	100.0	100.0
Ovendry	100.0	100.0	100.0

[1]These data, summarized from Koch (1987), are averages for trees 3, 6, and 9 inches in d.b.h. collected throughout the major range of var. *latifolia* in North America; that is, from 40 to 60 degrees latitude.

Cubic Volume of Lodgepole Pine Stemwood

In addition to knowledge of numbers of trees, it is useful to know something about the distribution of stemwood volume by diameter class in the three counties. Volume data for trees less than 5 inches in d.b.h. are unavailable; for lodgepole pines 5 inches in d.b.h. and larger on **commercial timberland**, stemwood volumes to a 4-inch top diameter outside bark can be summarized (from table 2-7) as follows:

County	National Forests	Other	Total
	M ft³ of stemwood		
Flathead	474,689.0	248,676.5	723,365.5
Lincoln	999,922.8	185,793.9	1,185,716.7
Sanders	550,969.4	91,837.0	642,806.4
Total	2,025,581.2	526,307.4	2,551,888.6

Thus, 79.4 percent of the cubic volume of lodgepole pine stemwood on commercial timberlands in these three counties is on acres administered by the National Forest System, and 20.6 percent is on other lands, that is, on lands owned by other public agencies, forest industries, and farmers or other private owners.

Of these total stemwood volumes, those represented by trees 5.0 to 8.9 inches in d.b.h. comprise 55.9, 58.2, and 57.2 percent in Flathead, Lincoln, and Sanders Counties, respectively. In other words, most of the stemwood volume is in sub-sawlog-size trees.

Available Lodgepole Pine Resource

The foregoing discussion has outlined the total lodgepole pine resource in Lincoln, Flathead, and Sanders Counties. More pertinent to this study is estimation of the acreages and volumes of lodgepole pine that are in suitable diameter classes and are potentially available during the next 20 years—a timespan approximately matched to anticipated plant life and to silvicultural objectives of the managers of National Forests in the area.

Trees suitable for the proposed operation should be less than 75 road miles from the plant site, in stands dominated by lodgepole pine, on slopes less than 55 percent, and in diameter classes generally spanning 3.0 to 8.9 inches—that is, in sub-sawlog or marginal sawlog diameters. Although there are no major technical difficulties in converting larger trees to structural flakeboard, it is deemed desirable to concentrate on the smaller trees as there is presently no major commercial use for small trees. Resource data on dead lodgepole pine are included in the event that conversion processes appropriate for dead timber can be developed.

At the time scheduled for stand replacement (harvest), truck-haul roads should be in place adjacent to the acreages (within one-fourth mile), and downslope from them.

Data on such available lodgepole pine are most accurately aggregated by National Forest rather than county. Less accurate are estimates of the available lodgepole resource on State and private lands.

Table 2-7—Volume of stemwood to a 4-inch top diameter outside bark in live lodgepole pine trees on commercial timberland in three Montana counties, by diameter class[1] and administrative class

Diameter class	National Forests	Other[2]	Total
		Ft³	
	Flathead County		
6	95,401,804	86,386,743	181,788,547
8	150,105,600	72,196,886	222,302,486
10	99,527,189	49,226,542	148,753,731
12	65,245,116	22,774,798	88,019,914
14	39,780,877	13,785,327	53,566,204
16	16,840,447	3,139,477	19,979,924
18	6,101,630	676,127	6,777,757
20	1,172,549	315,449	1,487,998
22	484,571	68,758	553,329
24	29,195	106,412	135,607
Total	474,688,978	248,676,519	723,365,497
	Lincoln County		
6	233,006,937	70,952,311	303,959,248
8	330,286,633	55,568,651	385,855,284
10	229,091,836	34,103,404	263,195,240
12	125,348,313	13,554,824	138,903,137
14	46,975,408	8,512,013	55,487,421
16	21,265,463	2,179,469	23,444,932
18	8,588,889	619,923	9,208,812
20	4,354,396	195,601	4,549,997
22	1,002,952	75,075	1,078,027
24	0	32,653	32,653
26	0	0	0
28	1,944	0	1,944
Total	999,922,771	185,793,924	1,185,716,695
	Sanders County		
6	129,084,108	24,562,918	153,647,026
8	182,592,953	31,447,468	214,040,421
10	122,034,982	17,183,812	139,218,794
12	71,290,880	10,179,138	81,470,018
14	26,184,872	5,311,933	31,496,805
16	13,347,245	1,546,860	14,894,105
18	3,836,231	302,624	4,138,855
20	1,725,473	1,004,389	2,729,862
22	539,343	297,869	837,212
24	332,772	0	332,772
26	0	0	0
28	513	0	513
Total	550,969,372	91,837,011	642,806,383

[1]Diameter classes (measured at breast height, outside bark) span 1.9 inches; for example, the 6-inch class spans from 5.0 to 6.9 inches. Data, based on survey information collected from 1966 to 1980, are from a special tabulation compiled by the Forest Survey Research Unit, Intermountain Research Station, Ogden, UT.

[2]State and other public, forest industries, and private ownerships.

Kootenai National Forest—The major available resource satisfying the requirements outlined under the foregoing heading lies within the Kootenai National Forest (table 2-8).

Excluding acreage dominated by live lodgepole pine sawtimber, and considering only stagnated, marginal sawlog, and dead sawtimber stands within 75 road miles of Libby on slopes less than 56 percent, more than half of the resource is in marginal sawlog stands, as follows (table 2-8; see table footnotes for stand definitions):

Stand type	Area	Stemwood weight, ovendry
	Acres	*Tons*
Stagnated	13,196	504,624
Marginal sawlog	29,312	1,192,686
Dead sawtimber	13,031	423,105
Total	55,539	2,120,415

About 60 percent of these 55,539 acres are roaded (as of 1987); that is, a road passes within one-fourth mile of the stands, as follows (table 2-8):

Stand type	Roaded	Unroaded
	Acres	*Acres*
Stagnated	9,418	7,405
Marginal sawlog	15,702	10,812
Dead sawtimber	8,160	4,042
Total	33,280	22,259

When acreages of all three of these lodgepole stand types on the Kootenai National Forest are summed, more than two-thirds of the acreage is within 40 road miles of Libby (table 2-9).

Table 2-8—Acres and ovendry tons[1] of lodgepole pine (stagnated, marginal sawlog, and dead sawtimber) available during the next 20 years from the Kootenai National Forest, related to slope, road distance from Libby, and road access (data from Kootenai National Forest, 1987)

Road status and road distance from Libby	Slope 0-20%	Slope 21-40%	Slope 41-55%	Totals	Average tons/acre
		Stagnated			
Roaded[2]					
<20 miles					23.6
Acres	33	606	0	639	
Tons	1,099	13,985	0	15,084	
21-40 miles					30.3
Acres	851	2,654	594	4,099	
Tons	21,926	85,371	16,885	124,182	
41-60 miles					32.1
Acres	959	693	91	1,743	
Tons	31,350	21,293	3,365	56,008	
61-75 miles					26.7
Acres	997	1,762	178	2,937	
Tons	23,284	45,238	7,090	75,612	
Totals					28.8
Acres	2,840	5,715	863	9,418	
Tons	77,659	165,887	27,340	270,886	
Unroaded					
<20 miles					28.0
Acres	49	221	610	880	
Tons	1,194	7,367	16,032	24,593	
21-40 miles					30.1
Acres	524	2,381	461	3,366	
Tons	10,751	78,670	11,749	101,170	
41-60 miles					34.6
Acres	573	851	614	2,038	
Tons	20,742	24,108	25,583	70,433	
61-75 miles					29.9
Acres	319	573	229	1,121	
Tons	7,230	17,090	9,153	33,473	
Totals					31.0
Acres	1,465	4,026	1,914	7,405	
Tons	39,917	127,235	62,517	229,669	
TOTALS (Stagnated)					29.8
Acres	4,305	9,741	2,777	16,823	
Tons	117,576	293,122	89,857	500,555	

(con.)

Table 2-8 (Con.)

Road status and road distance from Libby	Slope 0-20%	Slope 21-40%	Slope 41-55%	Totals	Average tons/acre
		Marginal sawlog timber			
Roaded[2]					
<20 miles					50.2
Acres	282	1,571	144	1,997	
Tons	9,377	88,632	2,149	100,158	
21-40 miles					33.5
Acres	1,475	3,287	2,602	7,364	
Tons	50,994	117,800	77,577	246,371	
41-60 miles					37.9
Acres	951	1,434	211	2,596	
Tons	33,187	57,094	8,101	98,382	
61-75 miles					38.1
Acres	1,703	2,008	34	3,745	
Tons	65,500	76,273	1,079	142,852	
Totals					37.4
Acres	4,411	8,300	2,991	15,702	
Tons	159,058	339,799	88,906	587,763	
Unroaded					
<20 miles					28.1
Acres	125	348	4,061	4,534	
Tons	4,247	11,600	111,363	127,210	
21-40 miles					37.5
Acres	311	2,211	1,562	4,084	
Tons	12,488	90,952	49,660	153,100	
41-60 miles					34.8
Acres	775	690	468	1,933	
Tons	30,912	18,481	17,908	67,301	
61-75 miles					35.1
Acres	0	244	17	261	
Tons	0	8,397	763	9,160	
Totals					33.0
Acres	1,211	3,493	6,108	10,812	
Tons	47,647	129,430	179,694	356,771	
TOTALS (Marginal sawlog)				35.6	
Acres	5,622	11,793	9,099	26,514	
Tons	206,705	469,229	268,600	944,534	
		Dead sawtimber			
Roaded[2]					
<20 miles					52.9
Acres	338	742	52	1,132	
Tons	18,633	37,576	3,633	59,842	
21-40 miles					56.0
Acres	2,194	3,912	519	6,625	
Tons	120,951	218,169	31,605	370,725	
41-60 miles					55.6
Acres	223	180	0	403	
Tons	11,435	10,962	0	22,397	
61-75 miles					—
Acres	0	0	0	0	
Tons	0	0	0	0	
Totals					55.5
Acres	2,755	4,834	571	8,160	
Tons	151,019	266,707	35,238	452,964	
Unroaded					
<20 miles					48.8
Acres	0	708	420	1,128	
Tons	0	34,038	21,000	55,038	

(con.)

Table 2-8 (Con.)

Road status and road distance from Libby	Slope 0-20%	21-40%	41-55%	Totals	Average tons/acre
21-40 miles					59.8
Acres	514	1,696	164	2,374	
Tons	29,324	103,282	8,410	141,016	
41-60 miles					48.7
Acres	0	540	0	540	
Tons	0	26,308	0	26,308	
61-75 miles					—
Acres	0	0	0	0	
Tons	0	0	0	0	
Totals					55.0
Acres	514	2,944	584	4,042	
Tons	29,324	163,628	29,410	222,362	
TOTALS (Dead sawtimber)					55.4
Acres	3,269	7,778	1,155	12,202	
Tons	180,343	430,335	64,648	675,326	
	Stagnated, marginal sawlog, and dead sawtimber aggregated				
Roaded[2]					
<20 miles					46.5
Acres	653	2,919	196	3,768	
Tons	29,109	140,193	5,782	175,084	
21-40 miles					41.0
Acres	4,520	9,853	3,715	18,088	
Tons	193,871	421,340	126,067	741,278	
41-60 miles					37.3
Acres	2,133	2,307	302	4,742	
Tons	75,972	89,349	11,466	176,787	
61-75 miles					32.7
Acres	2,700	3,770	212	6,682	
Tons	88,784	121,511	8,169	218,464	
Totals					38.8
Acres	10,006	18,849	4,425	33,280	
Tons	387,736	772,393	151,484	1,311,613	
Unroaded					
<20 miles					31.6
Acres	174	1,277	5,091	6,542	
Tons	5,441	53,005	148,395	206,841	
21-40 miles					40.2
Acres	1,349	6,288	2,187	9,824	
Tons	52,563	272,904	69,819	395,286	
41-60 miles					36.4
Acres	1,348	2,081	1,082	4,511	
Tons	51,654	68,897	43,491	164,042	
61-75 miles					30.9
Acres	319	817	246	1,382	
Tons	7,230	25,487	9,916	42,633	
Totals					36.3
Acres	3,190	10,463	8,606	22,259	
Tons	116,888	420,293	271,621	808,802	
TOTALS (Stagnated, marginal and dead)					38.2
Acres	13,196	29,312	13,031	55,539	
Tons	504,624	1,192,686	423,105	2,120,415	

[1]Derived from cubic-foot data and converted at 25 pounds of ovendry stemwood per cubic foot of green stemwood volume. Tonnage data for all three stand classes include only those trees 5 inches in d.b.h. and larger to a top diameter of 4 inches measured inside bark.

Stagnated stands are defined as having less than 2,000 bd ft per acre, Scribner scale.

Marginal sawlog stands have less than 5,000 bd ft, but more than 2,000 bd ft per acre, Scribner scale.

Dead sawtimber stands are defined as stands with more than 5,000 bd ft per acre, Scribner scale, in which trees are dead or infested with pine bark beetle and expected to die within 2 years.

[2]Within one-fourth mile of a road; these roads are not necessarily downslope from the acreages, but most are.

Table 2-9—Acres and percentage of acres dominated by lodgepole pine on the Kootenai National Forest that have stagnated, marginal sawlog, and dead sawtimber on slopes less than 56 percent, and that are within 75 road miles of Libby (data from Kootenai National Forest, 1987)

Distance from Libby	Stagnated	Marginal sawlog	Dead sawtimber	Total
<20 miles				
Acres	1,519	6,531	2,260	10,310
Percent	9.0	24.6	18.5	18.5
21-40 miles				
Acres	7,465	11,448	8,999	27,912
Percent	44.4	43.2	73.8	50.3
41-60 miles				
Acres	3,781	4,529	943	9,253
Percent	22.5	17.1	7.7	16.7
61-75 miles				
Acres	4,058	4,006	0	8,064
Percent	24.1	15.1	0	14.5
Total				
Acres	16,823	26,514	12,202	55,539
Percent	100.0	100.0	100.0	100.0

Only 13,031 acres (23 percent) of the total of 55,539 acres in these three stand types on slopes less than 56 percent are on terrain having slopes of 41 to 55 percent; 29,312 acres (53 percent) have slopes of 21 to 40 percent; and 13,196 acres (24 percent) are on slopes of 20 percent or less (table 2-8).

Western Portion of Flathead National Forest—Within 75 miles of the Libby-Troy area, the Flathead National Forest has 9,648 acres of similar lodgepole pine timber totaling 266,258 tons (ovendry basis) of stemwood (table 2-10). On average, these commercial timberlands have about 27.6 tons of stemwood per acre in trees 5 inches and larger in d.b.h. to a 4-inch top diameter measured inside bark. About 20 percent of the acres are within one-fourth mile of a road. Slightly more than half (54.3 percent) of the tonnage is in dead sawtimber stands, 41.5 percent in marginal sawtimber stands, and only 4.2 percent in stagnated sub-sawlog stands.

Northeastern Portion of Idaho Panhandle National Forests—The Bonners Ferry Ranger District of the Idaho Panhandle National Forests has, within 75 road miles of Libby-Troy, areas of similar lodgepole pine (9,700 acres) about equal to that on the Flathead National Forest. Because the threshold dimensions of trees included in the Idaho tabulation are larger than those in the Montana tabulation, tonnages are difficult to compare (see footnote 1 of table 2-10); if the Flathead criteria were applied to the Panhandle acreage, however, tonnages would probably be about equal. About 27 percent of the Idaho area is within one-fourth mile of a road. Most of the acreage (80 percent) is in marginal sawlog stands, and the balance is evenly divided betwen stagnated and dead timber (table 2-10).

State and Private Lands—As previously noted, outside of the National Forests there are about 269,796 acres of lodgepole pine forest type within the commercial timberlands of Flathead, Lincoln, and Sanders Counties. Of these non-National Forest acres, 17.3 percent are publicly owned, 61.0 percent are forest-industry owned, and 21.7 percent are owned by farmers and other private people.

All lodgepole volume in all types of stands—including sawtimber—on State and private lands in these counties totals 526,307,400 ft^3 of stemwood in trees 5 inches in d.b.h. and larger to a 4-inch top measured outside bark (table 2-3); this amounts to 6,578,842 tons of stemwood, ovendry basis.

Summary of Available Resource

The National Forest available lodgepole pine resource within 75 miles of Libby-Troy on slopes of 55 percent or less in stagnated, marginal, and dead stands can be summarized as follows:

National Forest	Acres	Stemwood in trees 5 inches in d.b.h. and larger to a 4-inch top inside bark
		Tons, ovendry
Flathead	9,648	266,258
Kootenai	55,539	2,120,415
Idaho Panhandle	9,700	266,258
Total	74,887	2,652,931

These data suggest that—averaging the three stand types—there are about 35.4 tons per acre of stemwood (ovendry) in trees 5 inches in d.b.h. and larger to a 4-inch top.

Additionally, State and private lodgepole pine lands in the three-county area (not necessarily available or within 75 miles of Libby-Troy, or on slopes of 55 percent or less) total about 269,796 acres, with a total stemwood weight (ovendry) of 6,578,842 tons. This tonnage includes live lodgepole sawtimber as well as the three less valuable classes of stands considered on the National Forests. Assuming that 5 percent of this acreage (that is, 13,490 acres) and this tonnage (that is, 328,942 tons) are economically available to a plant in the Libby-Troy area, then the total available resource in trees 5 inches d.b.h. and larger to a 4-inch top would be about 101,867 acres and 3,310,815 tons of stemwood (ovendry basis).

While somewhat more distant, there are similar stands—totaling perhaps 17,500 acres—that will be available over the next 20 years on the west end of the Lolo National Forest. The lodgepole pine stemwood in these stands might average about 35 tons per acre (ovendry basis), for a total of 612,500 tons to a 4-inch top inside bark.

Most of the roundwood (doweled) products envisioned for production use only those portions of lodgepole pine trees too small to be inventoried in all of the previous compilations; that is, those portions with a minimum top diameter inside bark of as little as $2^1/4$ inches, and a maximum butt diameter of perhaps $4^1/2$ inches inside bark. It seems reasonable to assume that these noninventoried tree portions total near 20 percent of the weight of the inventoried portions in the lodgepole stands under consideration.

All of these acres and tonnages, identified as available during the next 20 years, can be aggregated as follows:

Table 2-10—Acres and ovendry tons[1] of lodgepole pine in stagnated, marginal sawlog, and dead sawtimber stands available from the Flathead National Forest and Idaho Panhandle National Forests during the next 20 years within 75 road miles of Libby-Troy from slopes of 55 percent or less, related to road access (data from the Flathead and Idaho Panhandle National Forests, 1987)

Road status[2] and statistic	Subsawlog stagnated[3]	Marginal sawlog[4]	Dead sawtimber[5]	Totals	Average tons/acre
		Flathead National Forest			
Roaded					27.6
Acres	214	1,072	643	1,929	
Tons	2,220	22,083	28,935	53,238	
Unroaded					27.6
Acres	858	4,288	2,573	7,719	
Tons	8,902	88,333	115,785	213,020	
Total					27.6
Acres	1,072	5,360	3,216	9,648	
Tons	11,122	110,416	144,720	266,258	
Tons/acre	10.4	20.6	45.0	27.6	
		Idaho Panhandle National Forest (Bonners Ferry Ranger District)			
Roaded					13.5
Acres	1,000	1,600	0	2,600	
Tons	5,000	30,000	0	35,000	
Unroaded					17.7
Acres	0	6,100	1,000	7,100	
Tons	0	114,375	11,250	125,625	
Total					16.6
Acres	1,000	7,700	1,000	9,700	
Tons	5,000	144,375	11,250	160,625	
Tons/acre	5.0	18.8	11.3	16.6	

[1]Tonnages are derived from cubic-foot data and converted at 25 pounds of ovendry stemwood per cubic foot of stemwood volume. Tabulated Flathead National Forest data in all three stand classes are for trees 5 inches and larger in d.b.h. to a top diameter of 4 inches measured inside bark. Tabulated Idaho Panhandle data, however, includes trees defined as follows:

Stagnated: trees 6 inches in d.b.h. and larger to a 5-inch top outside bark.

Marginal and dead sawtimber: trees 9 inches in d.b.h. and larger to a 5-inch top outside bark.

[2]Roaded acreages are defined as those within one-fourth mile of a haul road; these roads are not necesarily downslope from the acreages, but most are.

[3]Subsawlog stagnated stands have less than 2,000 bd ft per acre, Scribner scale.

[4]Marginal sawlog stands have less than 5,000 bd ft, but more than 2,000 bd ft per acre, Scribner scale.

[5]Dead sawtimber stands are defined by the Flathead National Forest as stands with more than 5,000 bd ft per acre, Scribner scale, in which trees are dead or infested with mountain pine beetle and expected to die within 2 years. The Idaho Panhandle National Forests define dead sawtimber stands as having more than 60 merchantable—but dead—stems per acre.

Source	Available acres	Available weight of stemwood in trees 3 inches and larger in d.b.h. to a top diameter of 2¼ inches inside bark
		Tons, ovendry
Flathead NF	9,648	319,510
Kootenai NF	55,539	2,544,498
Panhandle NF	9,700	319,510
State and private	13,490	328,942
Lolo NF	17,500	735,000
Total	105,877	4,247,460

To be conservative, harvest from sub-sawlog-size and dead-timber stands in the Libby-Troy procurement area should be limited to perhaps 2,200,000 tons over the 20-year life of the proposed plant (110,000 tons, ovendry, annually), or 52 percent of the total just tabulated as available from these stand classes for which there is little or no demand. These tonnages of lodgepole pine tabulated as available (tables 2-8 and 2-10) are probably underestimated by about 7 percent because the data are based on a conversion factor of 25 pounds of ovendry stemwood per cubic foot of green stemwood volume; sampling in the Libby-Troy latitudinal zone suggests that a conversion factor of 26.8 pounds would be more realistic.

In assessing the adequacy of the raw material supply, it should also be recognized that trees of sawlog diameter—not only of lodgepole pine, but including other species—can be introduced into structural flakeboard without adverse effects. It is conservatively estimated that over 20 years of plant life, an additional 1,800,000 tons (90,000 tons, ovendry, annually) of such stemwood could be purchased at a cost somewhat less than the cost of harvesting sub-sawlog-size lodgepole pine.

In summary, the available wood resource in the Libby-Troy procurement area should be amply adequate for an annual plant consumption of stemwood totaling 200,000 tons, ovendry basis—110,000 tons of lodgepole pine not normally suitable for sawmill consumption, plus 90,000 tons of tree-length logs comprising a mixture of coniferous species, but including a major component of lodgepole pine—perhaps 50 percent.

2-4 SITE SELECTION

Selection of a plant site within the State of Montana was one of the conditions of this analysis. Beyond this proscription, site selection is most strongly influenced by location of the available wood supply, followed by need for rail transport of products to market. Additionally, the proposed plant should not be located where air pollution is currently a problem. Also, a stable workforce, equitable taxes, and availability of needed utilities are essential for the proposed plant.

Procurement Area

As previously discussed, in Montana the greatest concentration of available lodgepole pine suitable for the proposed multiproduct plant lies in Lincoln, Flathead, and Sanders Counties. To permit logging trucks to average three round trips per day—thereby avoiding excessive log transport costs—procurement-area radius should average 40 to 50 road miles and not exceed 75 road miles. Distribution of the lodgepole pine resource in northwestern Montana is such that a location in Lincoln County appears most central. Figure 2-4 shows the area of consideration and various features discussed in the following analysis.

Transport of Products to Market

The two major products of the proposed plant—structural flakeboard and fabricated joists—must be transported to distant markets primarily by rail. Some of the roundwood products, such as tree props, are customarily shipped to market by truck. The site selected must therefore be adjacent to a railroad and have ready access to major highways. Study of Montana's transport network (fig. 2-5) indicates that the plant—if it is to be in Lincoln County—must be sited along the Burlington Northern rail line. Because of limited level land unthreatened by the Kootenai River along the rail line east of Libby, potential plant sites are restricted to the ground adjoining the

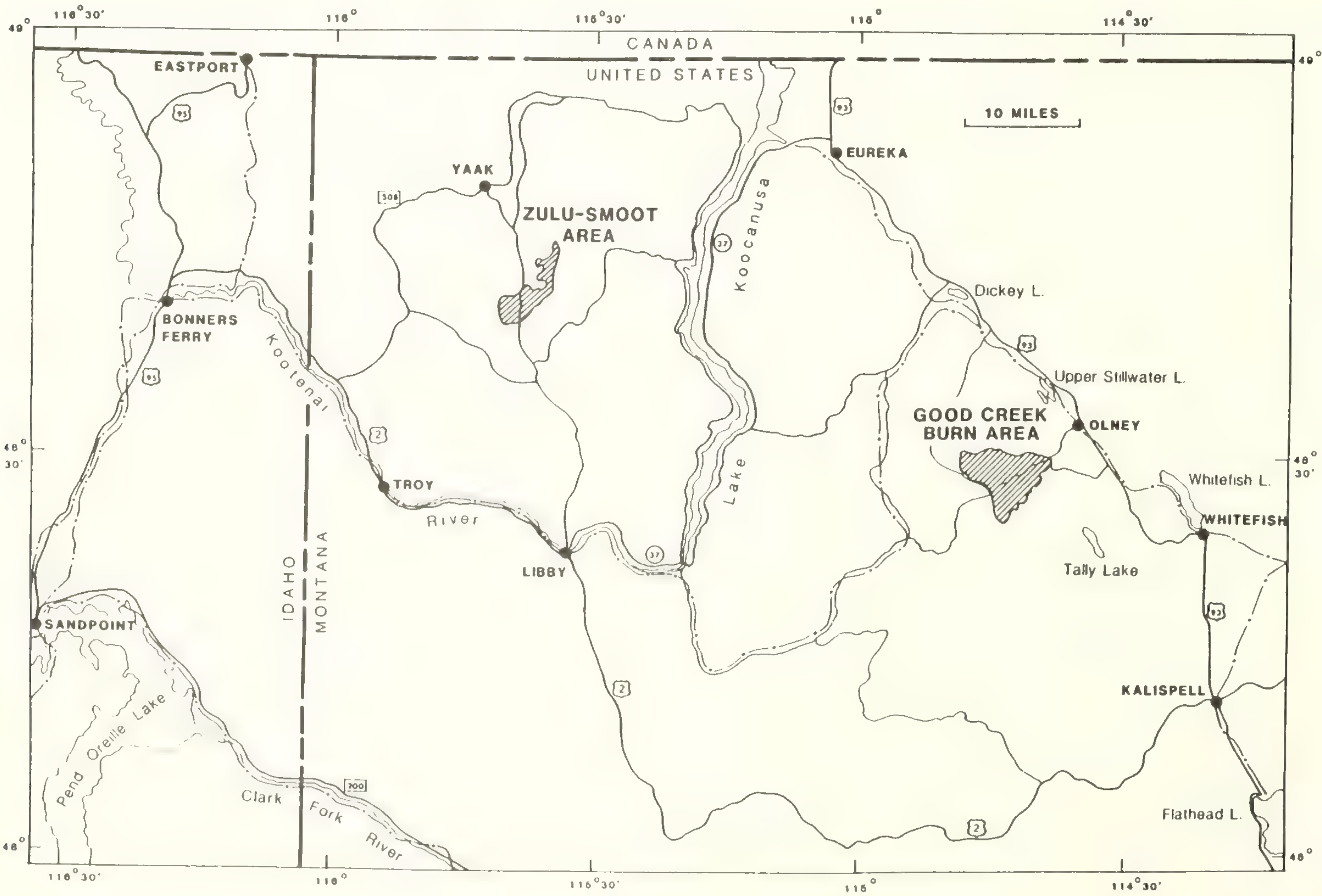

Figure 2-4—The Libby-Troy region of northwestern Montana. The procurement area contemplated has a radius of about 75 road miles from Libby-Troy, extending approximately from Bonners Ferry in the west, to near the Canadian border in the north, near Eureka in the northeast, Tally Lake vicinity in the east, and the map border in the south. The shaded areas are acreages of stagnated lodgepole pine that received special study in 1986.

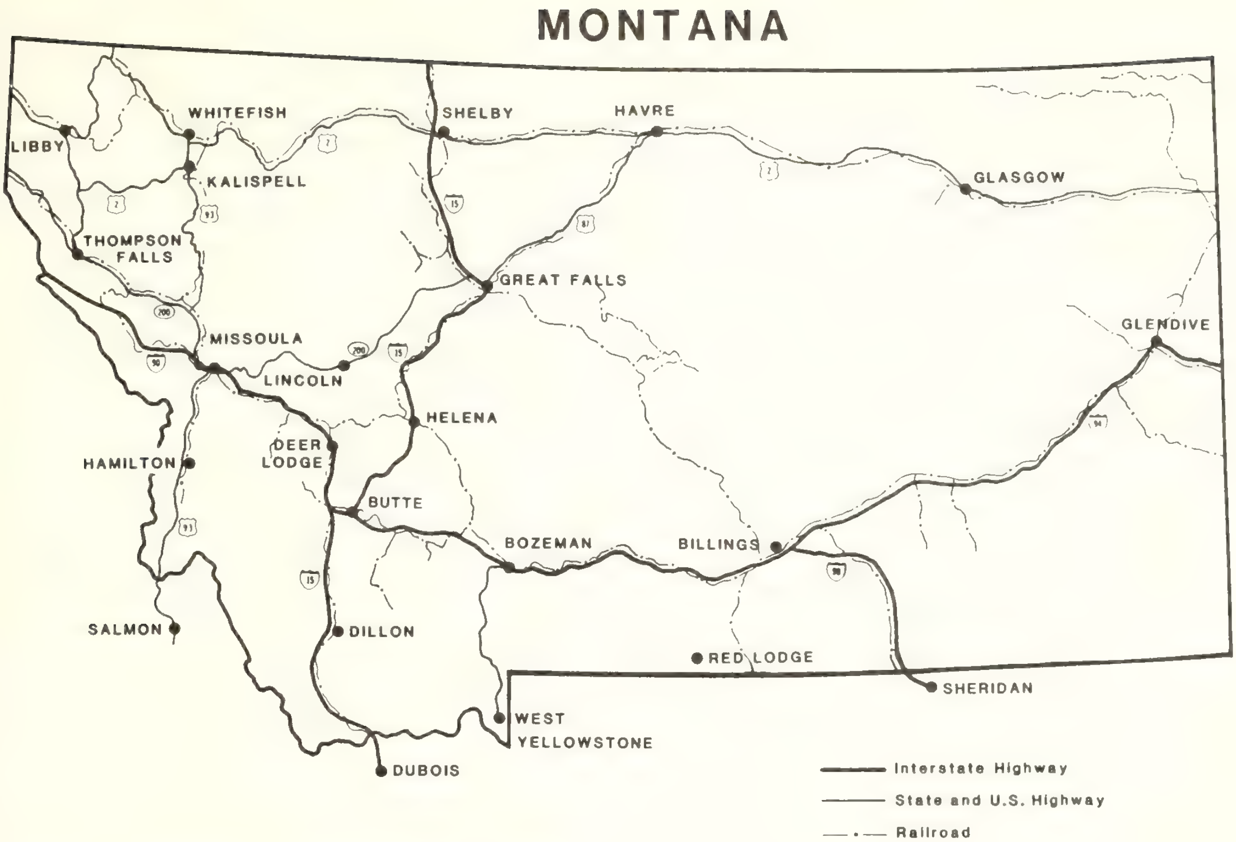

Figure 2-5—Railroads and principal highways in Montana.

railroad from the vicinity of Libby to the Idaho border. Moyie Springs, ID, 43 miles northwest of Libby, is a railhead on the Union Pacific line.

Other Considerations

Pollution Potential—Current levels of air pollution in the immediate vicinity of Libby suggest that if the plant is to be near Libby it should be 2 or 3 miles upstream to the east. Alternatively, the plant might be located adjacent to Troy, or 2 or 3 miles northwest of Troy along the Kootenai River.

Climate—Libby lies at 2,000 feet elevation, has a mean annual precipitation of 18.85 inches, mean annual snowfall of 55.6 inches, and average wind velocity of 2 mi/h. It is in an inversion area. Climate is less severe in Libby than in the rest of Montana, with mean daily maximum temperatures of 30 °F in January and 90 °F in July. Troy has an elevation of 1,889 feet, mean annual precipitation of 23.6 inches, mean annual snowfall of 47.3 inches, and average wind velocity of 5.3 mi/h.

Labor Supply in Procurement Area—Lincoln County has a total population of 18,160 (1980 census). Unemployment during 1986 averaged 11.5 percent of the county workforce; for the same period the entire State of Montana had an unemployment rate of 8.1 percent. The county seat of Libby is the largest community in the county, with 2,748 people within the town limits and 10,960 within a 4-mile radius. Troy has a population of 1,084 within the town limits and 4,200 including adjacent area. In 1986, sawmills in the area employed about 550 workers.

Forest Products Industry in the Vicinity—There is a major sawmill and plywood manufacturing complex located in Libby, but it is not presently designed to process sub-sawlog-size lodgepole pine. Three sizable sawmills manufacturing random-length dimension lumber are located near Eureka, but they are not designed for sub-sawlog-size lodgepole pine.

Two sizable mills manufacturing 2- by 4-inch studs are located near Bonners Ferry (the one at Moyie Springs draws considerable lodgepole pine sawtimber from the Yaak area); there is also a large stud mill at Olney, which cuts lodgepole pine almost exclusively. Also, there is a small sawmill located between Yaak and Troy. In January 1988, announcement was made of plans for a new sawmill in Libby to produce green lodgepole pine studs for shipment to Moyie Springs for drying and planing.

Manufacturers of roundwood include a post and pole operation near Bonners Ferry and a house log producer near Eureka. The nearest pulp mill is near Missoula, about 190 miles from Libby. A medium-size structural flakeboard plant utilizing lodgepole pine is located at Chilco, ID—about 125 miles from Libby.

Utilities—At any of the five identified potential plant sites adjacent to the railroad near Libby and Troy, water for plant operation appears to be available from the Kootenai River. Spent process water from the plant would likely have to be evaporated or settled from ponds, rather than returned to the river.

Pacific Power and Light Company has a power line adequate to serve the operation within one-fourth mile of a potential plant site a few miles east of Libby. Sites near Troy are out of this company's service area.

A potential plant site immediately adjacent to Troy could be served by Montana Light and Power—a subsidiary of Champion International, Inc.; adequacy of this power supply for the continuous operation contemplated is doubtful, however.

Northern Lights, Inc., also serves the Troy site and other sites downstream (northwest) of Troy. This company has a substation just east of Troy on the west side of the river and power lines running northwest; downstream from Troy they are on the north side of the Kootenai River. Northern Lights has available power adequate for the proposed operation and maintains a two-person crew staffing an Outlying Service Area in Troy.

Natural gas is unavailable at any of the potential sites in the Libby-Troy area.

A rail siding is in place at the potential site in Troy, but at other potential sites a rail siding would have to be constructed. Difficulties in accomplishing such siding construction along this main line of the Burlington Northern have yet to be assessed.

Property Tax Incentives—Under a local-option industrial tax incentive, new industrial properties pay significantly reduced property taxes during the first 3 years of operation, and somewhat reduced taxes for years 4 through 9 on a schedule under which the property is fully taxed by the tenth year.

Community Attitudes—The Lincoln County Development Council, headquartered in Libby, works actively to encourage industrial growth in the county. Residents in Libby and Troy appear to be supportive of new and existing forest-based industries in the area.

City Governments—Both Libby and Troy have mayor/council-type governments. Libby has a city zoning ordinance in effect, but Troy does not. Both communities are served by volunteer fire departments and ambulance services.

Medical Services—Libby has a 34-bed hospital, a 64-bed convalescent center, and a mental health center. In 1986 the Libby area had 10 doctors, six dentists, two veterinarians, three chiropractors, and two optometrists. Troy has a medical clinic staffed by one doctor. Additionally, there is one dentist and one chiropractor in the community.

Amenities—Recreational opportunities in the Libby-Troy area include access to the Kootenai National Forest and the Cabinet Mountain Wilderness Area. The Kootenai River is adjacent to both communities, and Lake Koocanusa is only a few miles east of Libby. Other major lakes in the area include Bull, Savage, Spar, and Kilbrennan.

The area provides excellent fishing and hunting opportunities, and community facilities include golf courses, tennis courts, bowling alleys, and city parks.

The Libby area has four elementary schools, one junior high school, one high school, three private schools, and a community college. The Troy area has four elementary schools, a junior high school, a high school, and one private school; the area is served by the Flathead Valley Community College extension program. Libby has 20 churches, and Troy has nine. Both communities have free county libraries.

Other—The State of Montana Job Service Office in Libby can assist in recruitment of workers for jobs described by the employer. In addition, the Montana Department of Labor and Industry has funds available for startup training programs and also for on-the-job training. Up to $41,000 is available for startup training needs for new employers. Typically during on-the-job training, the employer pays 50 percent of the wages, and the State pays 50 percent during the training period—which can extend up to 3 months.

Conclusions

The need to be on a railroad and centrally located in respect to an adequate timber resource suggests selection of a Lincoln County site in the Libby-Troy area (fig. 2-4). Air pollution potential in the area is a consideration in plant location, but it is believed that there are at least five potential sites available adjacent to the Burlington Northern railroad and the Kootenai River. These sites range in size from 40 to 200 acres. The Lincoln County Economic Development Council has additional descriptive data on these sites. For the purposes of this analysis, it is sufficient to conclude that a suitable site can be acquired in the Libby-Troy area.

Also available for consideration are three acreages owned by the State of Montana. These potential sites are near the confluence of the Kootenai and Fisher Rivers east of Libby and south of Lake Koocanusa (fig. 2-4). All have access to the Burlington Northern rail line, although one would require construction of a short spur line.

2-5 PROCUREMENT, HARVESTING, AND TRANSPORT PROCEDURES

Procurement

At the outset it should be understood that the major contemplated operation in the forest is a stand replacement, not a timber sale. That is, the company planning to utilize the biomass will—in a no-cost exchange for most of the biomass on each acre—agree to:

- Build the necessary minimum-quality, short, temporary access roads to perform the required clearcuts prescribed by the National Forests' long-range management plans. At least in the initial decade of the plan, these clearcuts will be made on land having slopes of 55 percent or less. It will be the responsibility of the land managers to construct the principal haul roads serving the areas.
- Shear (or saw-fell) and remove from the forest essentially all of the aboveground biomass of all trees of all species larger than 3 inches in d.b.h. (with the exception of some of the cone-bearing branches to favor regeneration). If the stand lacks sufficient viable seed, it will be the responsibility of the public land manager to supplement the seed by direct seeding at the appropriate time.

- Trample all stems 3 inches and less in d.b.h. This should result in less than 25 tons (ovendry basis) of slash on the ground. This slash will be neither piled nor burned, but simply be compacted by trampling and subsequent snowfall.
- Equip feller-bunchers and skidders with tracks designed to expose a maximum of mineral soil to favor natural regeneration. On areas where insufficient mineral soil was exposed because they were logged in deep snow, or for other reasons, it will be the responsibility of the land manager to roller chop—or otherwise adequately prepare the seedbed—according to prescription.
- To avoid unnecessary drain on the forest nutrient pool, restrict pile and burn operations to landings only, where slash may accumulate.

Harvesting

Steep-slope feller bunchers equipped with accumulators and shears or saws (fig. 2-6), each teamed with a forwarder (fig. 2-7) capable of operating on slopes up to 55 percent will comprise the primary harvesting equipment. For less steep ground, less expensive feller bunchers, each teamed with a pair of grapple skidders, will be used. In addition to felling, bunching, and forwarding (average of 2,000 feet for the forwarders and 700 feet for the skidders) about 900 trees per 8-hour day (an average maintained for 243 days out of the year), these vehicles should be able to effectively trample most of the small trees during all seasons, and expose mineral soil for seeding under all but deep-snow conditions. Trees forwarded or skidded to roadside will be loaded onto trucks (fig. 2-8) with a mobile grapple shared by each pair of feller bunchers.

Transport of Trees to Plant

Trees from most acreages will have small crowns and will be transported to the mill (fig. 2-8) with crowns attached. Stems from some stands will have such heavy crowns that they will require delimbing prior to transport, but this requirement will be unusual.

Alternatively, if biomass from branches proves in excess of needs for plant thermal energy (see page 70), at additonal cost all trees could be mechanically stroke-delimbed at landings prior to loading on trucks.

Trees will be offloaded by crane at the plant, stored in high decks, and water-sprayed in summer when risk of fungal stain is high.

Cost of Harvest and Transport

A cost analysis of harvest and transport operations (appendix II) indicates that whole trees (entire above-ground tree portions, including branches and foliage) can be harvested and loaded on log trucks for about $35 per ton (ovendry basis) of stemwood, assuming that bark, branches, and foliage bear no cost burden. This includes

Figure 2-6—Track-mounted steep-slope feller buncher equipped with self-leveling platform carrying a boom-mounted shear (or saw) that can accumulate severed stems preparatory to depositing them in a bunch. (Photo from Koch 1987.)

Figure 2-7—Forwarder capable of transporting whole trees from stump to roadhead.

15 percent interest on entire capital cost, which roughly corresponds to a 15 percent profit on total investment in harvesting and support equipment. The $35 cost is derived from data in appendix II under the assumption that the smallest tree harvested will be 3 inches in d.b.h. with few over 8.9 inches in d.b.h., and that 44.7 percent of the trees will be in the 4-inch diameter class, 36.6 percent in the 6-inch class, and 18.7 percent in the 8-inch class (see the Lincoln County data in table 2-4).

In addition to the wood harvested and transported, as illustrated in figures 2-6, 2-7, and 2-8, from National Forest land, additional wood will be purchased from independent contractors operating on State and private land. The proportion of total cubic-foot volume of lodgepole pine growing stock on State and private lands is 34.4 percent in Flathead County, 15.7 percent in Lincoln County, and 14.3 percent in Sanders County (table 2-3). It is estimated that 80 percent of the total wood harvested will come from National Forests and 20 percent from State and private lands.

Transport costs, including profit on equipment investment, should be about $11 per ton of stemwood, ovendry basis. This estimate is based on a cost of $1.34 per round-trip mile over an average haul radius of 40 road miles, with a 26-ton load of green, whole trees containing $9^3/4$ tons of stemwood, ovendry basis.

Total cost, including profit on investment, for harvesting and hauling will therefore be about $46 per ton of ovendry stemwood (that is, $35 + $11). To this must be added about $1.25 per ton for administration of the procurement operation, yielding a total of $47.25 per ton of ovendry stemwood delivered to the plant. Under this costing system, bark and branchwood enter the plant at zero cost.

Organization of Wood Procurement Operation

The wood procurement operation will be set up as a corporation separate from the manufacturing corporation. The procurement corporation will do no harvesting with corporate crews, but will contract all harvesting operations. Most contractors will operate on a large scale, as described by figures 2-6 and 2-7. Others may use lighter and less expensive equipment, however.

In addition to the just-described contracted stand-replacement harvests from National Forests, it is anticipated that significant tonnages of woods-run, tree-length logs of mixed coniferous species will be purchased on the open market from independent loggers at a cost slightly lower than that computed for the stand replacement harvests. The cost of such purchased wood is estimated at

Figure 2-8—Whole pines with small crowns being grapple loaded on a truck for transport to mill.

$40 per ton of ovendry stemwood delivered to the plant, plus $1.25 per ton for administration of the wood procurement operation, for a total of $41.25 per ton.

2-6 SUMMARY

Data discussed in this chapter suggest that the optimum Montana location for the operations contemplated is in the Libby-Troy area (fig. 2-4) of Lincoln County, and that plant consumption of stemwood (ovendry weight basis) should probably not exceed 200,000 tons annually.

About 55 percent of this tonnage will be tree-length lodgepole pine stemwood not suitable for sawmills; the balance will be tree-length wood of mixed coniferous species (perhaps half lodgepole pine), some of which may be of sawlog size and quality.

The average cost of stemwood delivered to the plant should be about $47.25 per ton, ovendry-weight basis, for that harvested in stand-replacement operations. The purchased wood should cost about $41.25 per ton of stemwood, ovendry-weight basis. Overall average cost of wood should therefore be about $44.55 per ovendry ton, that is:

$$(110{,}000 \text{ tons} \times \$47.25 + 90{,}000 \text{ tons} \times \$41.25) \div 200{,}000 = \$44.55.$$

2-7 REFERENCES

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CHAPTER 3: PRODUCT MIX AND MATERIAL BALANCES

CONTENTS

3-1 WOOD CHARACTERISTICS

There are good reasons why lodgepole pine can be an important source of raw material for a broad range of products. First—as noted in chapters 1 and 2—substantial volumes of the timber are available now, and the resource is readily and economically renewable in pure stands over a broad range of sites. Second, the wood itself has an unusual combination of desirable properties, especially that grown in northwestern Montana.

The strength/weight ratio of lodgepole pine is outstanding, particularly in small-diameter, suppressed trees typical of those in most Montana stands—and these small-diameter trees do not have the large core of weak, short-fibered, distortion-prone juvenile wood so prevalent in many commercially important conifers of North America. When of sufficient size, lodgepole pine is a prime material for structural plywood and laminated-veneer lumber; trees of smaller diameter yield flakes admirably suited for structural flakeboards such as waferboard, oriented-strand panels, and oriented-strand lumber. Its light color and long fibers make it well suited for conversion to fiberboard products such as hardboard and medium-density fiberboard. For the same reasons, it is well adapted for pulping by both chemical and mechanical processes. Also, it is a premium species for the manufacture of 2 by 4 studs, and machine-stress-rated lumber for trusses. Further, the form of the trees favors their broad acceptance for rails, posts, small poles, and logs for cabins. The small branches and self-pruning attribute of the species facilitate manufacture of attractive, sound-knotted paneling and millwork; most consumers find esthetically pleasing the faint dimpled pattern visible on tangentially cut millwork surfaces of lodgepole pine. Among all North American species, lodgepole pine ranks near the top in compatibility with Portland cement, thus making it a favored candidate for wood-cement composite panels.

Small stem diameter is the principal factor limiting use of the species. Also, heartwood of lodgepole pine ranks among the least permeable of major commercial coniferous species in North America. Although knots in lodgepole pine are small and unobtrusive, they do tend to be dark—even black—in many stems. If red-knotted wood is required for a product, some visual grading of stem sections must precede manufacture. Also, spiral grain is occasionally severe in some stems; on kiln drying, such spirality may cause twist in both sawn and roundwood products.

3-2 POTENTIAL PRODUCTS

The need to clear-fell trees of all diameters and all species, and to utilize all those exceeding 3 inches in d.b.h. (see section 2-5) constrains product selection, as does the generally small diameter of even the largest stems. Because of the small average stem diameter, and the significant component of dead timber in the stands available, concentration on products utilizing rotary-cut veneer is deemed impractical—even if centerless lathes are employed.

Because of the magnitude of investment and resource required for pulp and paper production, and because of environmental considerations, manufacture of chemical pulp is perhaps not possible. Also for environmental reasons, wet-process fiberboard production is not considered a viable option. Favoring pulp or fiberboard production, however, is the availablity of low-cost pulp chips from sawmill residues in northwestern Montana.

After elimination of pulp and paper, wet-process fiberboard, and structural veneer products, there still remains a broad spectrum of potentially viable products. One way of screening these products is estimation of their plant-gate net sale price per ton, ovendry-weight basis (table 3-1). This information, along with estimation of product yield as a percentage of gross stemwood weight, evaluation of cost of the manufacturing operation, and value analysis of residues produced, provides some guidelines for rational selection of products.

Net sales realization per ton of stemwood input (ovendry basis) varies widely with product; also, labor input per product ton varies significantly. A summation of product net plant-gate prices (after deducting costs of resin and wax content) per ton of wood content, multiplied by the ratio of product output to stemwood input, less estimated labor cost per product ton (table 3-2), suggests the following order of manufacturing priority for profit potential (listed with greatest profit potential at top and least potential at bottom—without consideration of capital costs, energy costs, or other operating and administration costs):

Product	**Net sales revenue minus cost of resin and labor**
	Dollars per oven dry ton of stemwood input
2-inch tree props (doweled)	$158
$2^5/_8$-inch rails and tree props (doweled)	137
Edge-glued solid lumber panels	118
2 by 10 oriented-strand lumber	115
Fabricated pole joists	113
$^7/_{16}$-inch OSB sheathing	91
2 by 4 kiln-dried studs	49
8-foot 1 by 6 kiln-dry lumber	16
Pulp chips	15

Table 3-1—Product comparisons by volume, weight, net plant-gate sale price, and recovery ratio

Product	Volume	Sale price on a volume basis	Proposed product weight[1]	Net plant-gate sale price wood only[2]	Weight ratio of product output to stemwood input
	Ft³	*Dollars*	*Pounds ovendry*	*Dollars per ton*	*Percent yield*
Pulp chips	96	22	2,400	18	95
	- - - - - - - - - - - - - per unit - - - - - - - - - - - - - -				
7/16-inch flakeboard	36.5	130	1,422	156	80
	- - - - - - - - - - - per thousand ft² - - - - - - - - -				
2 by 10 structural lumber	59.4	240	2,234	189	79
	- - - per M bd ft - - - -		- - - - - - - - - - oriented-strand lumber - - - - - - - - - -		
2 5/8-inch doweled tree props and rails	37.6	150	1,009	297	60
	- - - - - - - per thousand lineal feet - - - - - - - -				
8-ft 1 by 6 boards	57.3	150	1,433	209	33
	- - - - - - - per M bd ft, solid-sawn - - - - - - - - -				
2 by 4 studs	54.7	180	1,368	263	33
	- - - - - - - per M bd ft, solid-sawn - - - - - - - - -				
2-inch tree props	21.8	95	572	332	60
	- - - - - - - per thousand lineal feet - - - - - - - -				
Fabricated pole joists	85.2	700	2,575	500	45
	- - - - - - - per thousand lineal feet[3] - - - - - - - -				
Edge-glued solid lumber panels	125.0	750	3,588	401	50 (after shaping-lathe round-up)
	- - - - - - - per thousand ft² 1.5 inches thick - - - - - - - -				

[1]Wood only, exclusive of resin and wax.
[2]After deducting cost of resin and wax.
[3]Assumes two lineal feet of 12-inch-deep joist produced for each foot of 10-inch-deep joist.

Table 3-2—Estimation of net sales realization, by product, per ton of stemwood input (ovendry weight basis) after deducting costs of resin, wax, and labor (including common services and management)

Product	Percent yield multiplied by product sale price per ton (from table 3-1)	Estimated labor input per ton of product	Percent yield multiplied by (sale price less labor cost at $12.50 per hour)
	Dollars per ton, ovendry	*Worker-hours*	*Dollars per ton of stemwood input, ovendry*
2-inch tree props	$199	3.3	158
2 5/8-inch rails and tree props	178	3.3	137
Edge-glued solid lumber panels	200	6.6	118
2 by 10 oriented-strand lumber	149	2.7	115
Fabricated pole joists	225	9.0	113
7/16-inch OSB sheathing	125	2.7	91
2 by 4 kiln-dried studs	87	3.0	49
8-foot 1 by 6 kiln-dried lumber	69	4.2	16
Pulp chips	17	.2	15

These data, and knowledge that most stem sections are of sub-sawlog size, suggest that this analysis should concentrate on structural flakeboard (for market, probably oriented-strand board because orientation of face and core layers is the most economical way of obtaining needed mechanical properties), possibly oriented-strand lumber, tree props (rails and posts, while not unattractive in price are sold mostly in local markets), fabricated joists, and edge-glued lumber millwork panels (figs. 3-1 through 3-7).

The remainder of this chapter discusses these potential products and estimates material balances resulting from their manufacture.

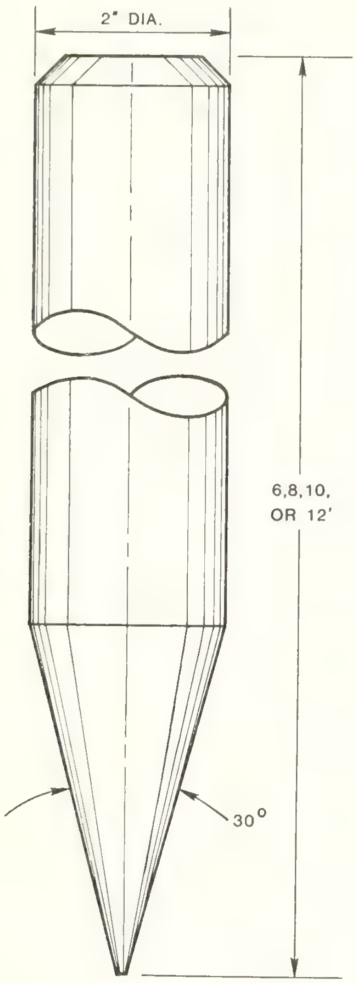


Figure 3-1—Dimensions of 2-inch tree prop.

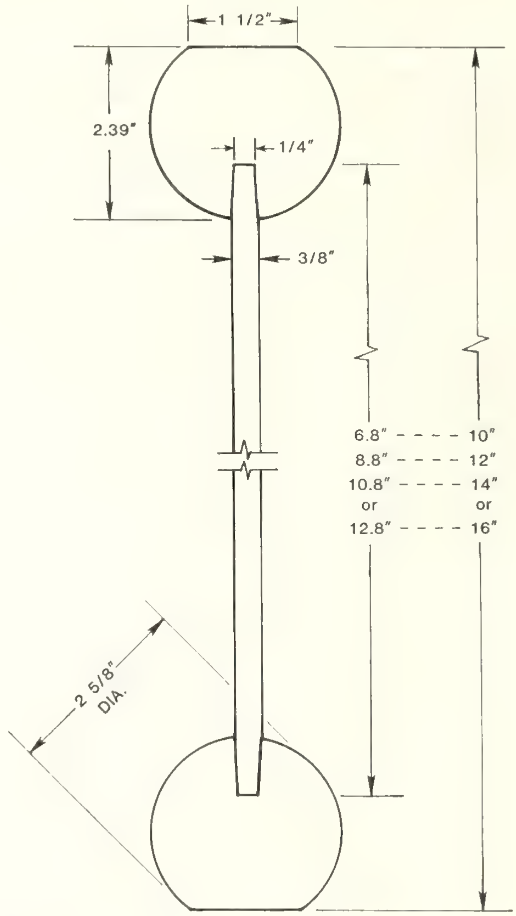


Figure 3-2—Proposed commercial designs of pole joists 10, 12, 14, and 16 inches in depth. Flanges are pith-centered lodgepole pine dowels; webs are $^3/_8$-inch-thick structural flakeboard.

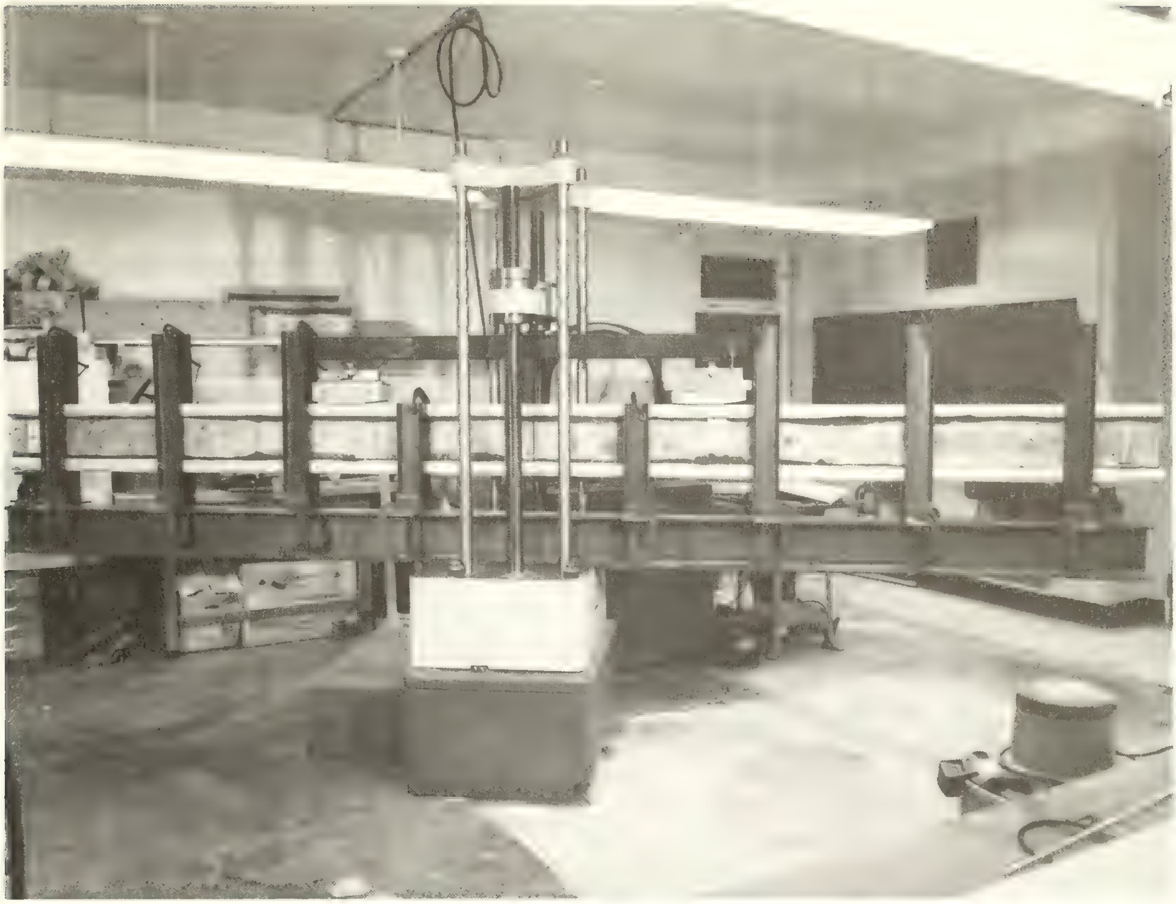


Figure 3-3—Fabricated pole joist 16 feet long undergoing a destructive bending test with third-point loading over a 15-foot span.

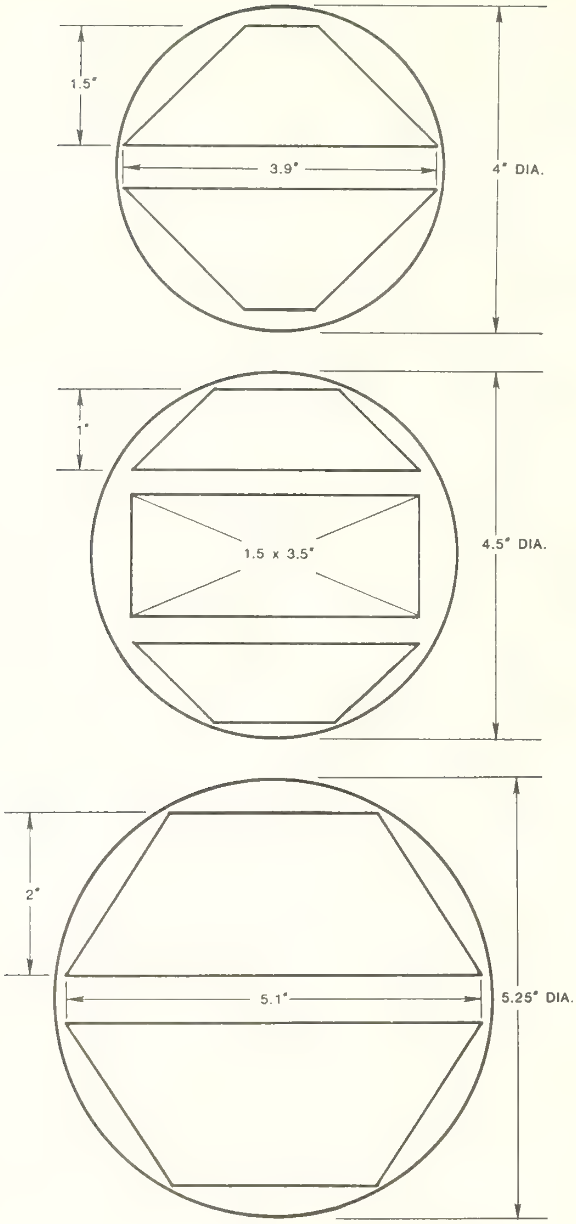
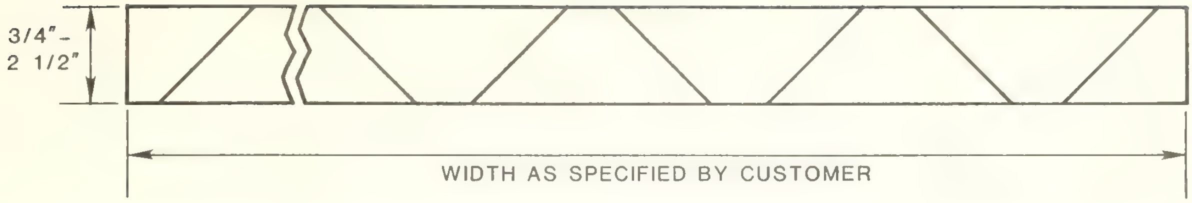


Figure 3-4—Typical small-log cutting patterns designed to yield kiln-dried, fully machined trapezoidal shapes for utilization in edge-glued panels; to simplify the drawings, toothing on the beveled edges is not shown. Diameters indicated are for kiln-dry half-cylinders; green dowels, before resawing, would be about 0.2 inch larger in diameter.



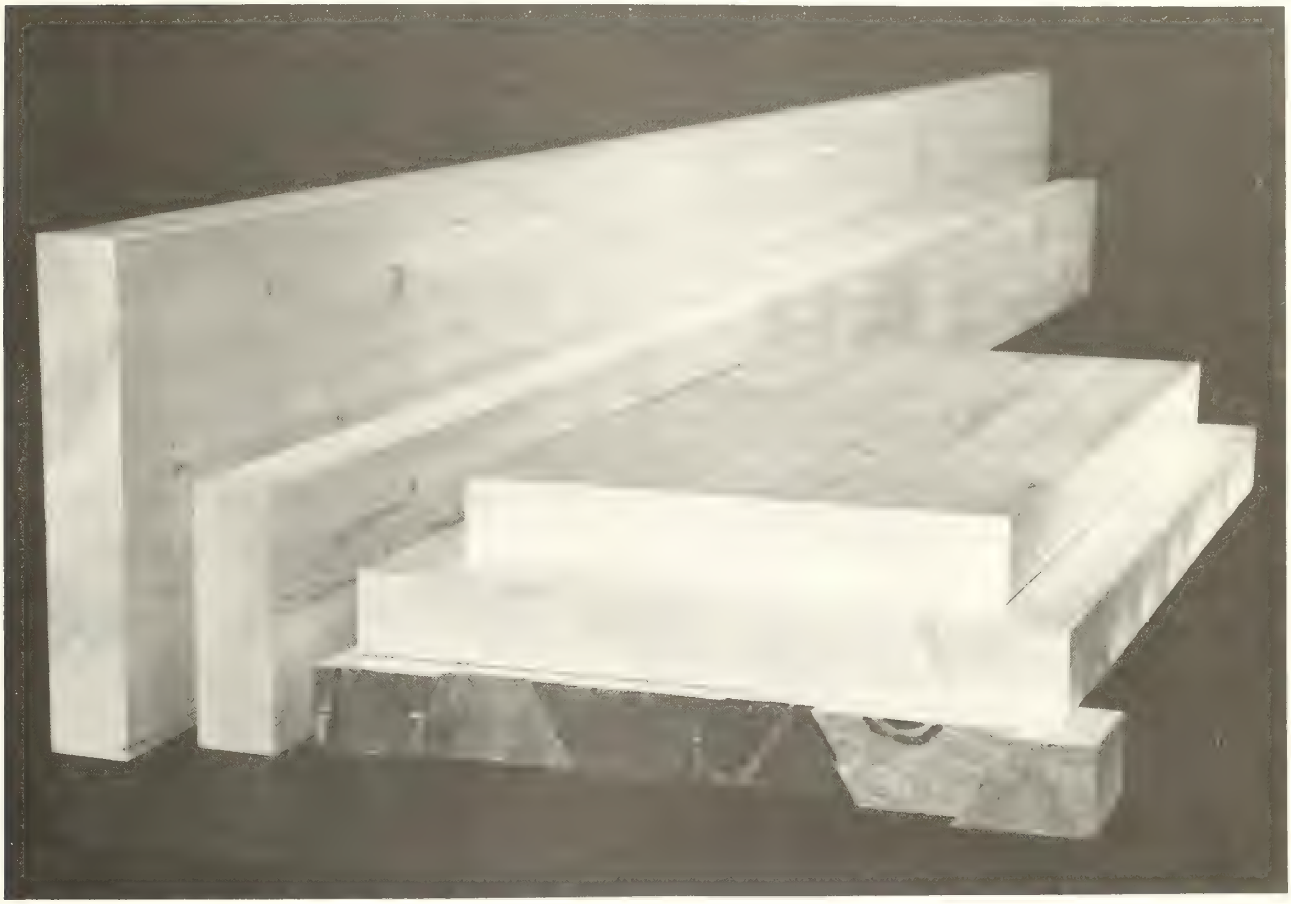


Figure 3-5—(Top) Panel cross section showing geometry of assembly. (Bottom) Glue lines in the completed panels are nearly invisible; knots are typically small, sound, and distributed over both surfaces.

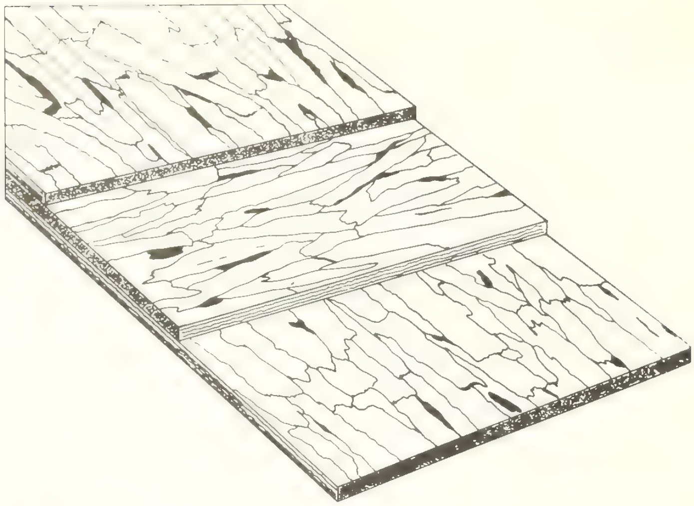


Figure 3-6—Structural three-layer oriented-strand board; flakes in the two face layers are aligned with grain parallel to the long edge of panels as they are pressed—for example, in 8-foot-wide by 32-foot-long size; those in the core are at right angles to this.

Figure 3-7—Oriented-strand board installed as floor decking (foreground) and wall and roof sheathing (typically $^{7}/_{16}$ inch thick) on a residence; shingles will be installed over the roof sheathing.

Composite Panels

Structural flakeboard products such as waferboard, oriented-strand board (figs. 3-6 and 3-7), and oriented-strand lumber can be advantageously manufactured from the available resource. Manufacture of such products, while capital-intensive, requires relatively low labor and power input; moreover, a high proportion (about 80 percent) of the weight of stemwood sections admitted to the process can be converted into products with a net plant-gate sale value of perhaps $175 per ton, ovendry. The sale value of $175 per ton includes about $19 of wax and phenol-formaldehyde (P/F) resin, leaving a net of about $156 per ton of ovendry wood in the product. The process requires raw material in roundwood form—as opposed to wood in pulp-chip or other particulate form—and it is therefore not suited for utilization of residues from other manufacturing operations. It is also recognized that fixed-disk flakers should be fed bolts larger than 4½ or 5 inches in diameter if standard productivity is to be maintained. Moving-head flakers (disk or drum) capable of flaking bundles of random-length logs can accommodate stems of smaller diameter, but the quality of flakes cut from very small stems will likely be lower than the quality of those cut from larger wood.

Dry-process medium-density fiberboard (MDF) does not require roundwood furnish; while basically manufactured from pulp chips, its furnish can accommodate significant quantities of coarsely hogged wood (even including some bark), shavings, and coarse sawdust. Thus, in a multiproduct manufacturing operation, the residues from other products can be incorporated in MDF to boost overall product yield—a significant advantage. MDF has a net plant-gate sale value of about $189 per ton of ovendry board; while this value appears high in relation to structural flakeboard, it contains a large increment of power cost—perhaps $27 per ton—as well as significant resin cost. As a result, the net per ton of ovendry wood in the product is not greatly different from that for flakeboard. Moreover, the very large energy demand of the required defibrators (perhaps 3.5 megawatts for a plant of viable size), suggests that any such plant generate its own power from wood residues—thus adding to the complexity of the plant and significantly increasing capital costs.

The markets for both MDF and structural flakeboard are expected to grow significantly in the next few decades (chapter 9); however, the market for MDF is primarily tied to the furniture industry—mostly located far distant from Montana in the Southeast, the Northeast, and southern California. The market for structural flakeboard, in contrast, is primarily tied to the residential housing market throughout the United States, and Western States are expected to show more than average growth in housing starts. Moreover, the market for structural flakeboard (tons sold) is several times larger than that for MDF. Currently there is one plant manufacturing MDF in Columbia Falls, MT; there are no manufacturers of structural flakeboard in the State. In spite of the significant advantage of the MDF process in absorbing other manufacturing residues, structural flakeboard—particularly oriented-strand board (fig. 3-6)—appears to be the better choice.

An entrepreneur with markets for MDF, however, might more closely study the tradeoffs between the manufacture of MDF and structural flakeboard. For a multiproduct plant with a total intake of 200,000 tons, ovendry, of stemwood (fig. 3-8), selection of MDF rather than flakeboard could boost composite panel production—through incorporation of residues from other plant manufacturing operations—by about 35,000 tons annually, and would add perhaps $5 million to annual sales. With an inhouse generating facility, power purchases would be diminished by about $1 million (from those incurred manufacturing flakeboard and the product mix shown in figure 3-8). Offsetting these gains are the capital costs and operating costs of a 7- or 8-megawatt generating facility.

Another possibility is manufacture of wood-cement composite panels (there is a cement plant in Metaline Falls, WA, with convenient truck and rail access to the Libby-Troy area). Lodgepole pine ranks near the top among North American species in compatibility with Portland cement (Moslemi and Pfister 1987). Although wood-cement composite panels are widely used in Europe, Mexico, and other regions where high material resistance to fire, insects, and decay is required, there are no manufacturing facilities in the United States.

Typically wood/cement ratios are about 1:3 on an oven-dry-weight basis. Green wood residues (such as those from doweling machines) can be utilized without drying, as the process needs water for hydration of the cement binder. Panels are typically cold pressed and air cured in ½-inch thickness to a density of about 80 lb/ft^3. Panel modulus of elasticity is typically in the range from 650,000 to 850,000 lb/in^2, and modulus of rupture in the range from 2,000 to 2,400 lb/in^2.

The high density of wood-cement composite panels would probably limit market radius to the Missoula-Coeur d'Alene-Spokane-Sandpoint area. At a plant-gate net sale price of $120 per ton of ½-inch panel ($200 per M ft^2), the margin remaining for the wood component and all manufacturing costs and profit would be about as follows:

Wood-cement composite panel price per ton	$120
Cost of cement (1,500 pounds) in a ton of panel	56 (at $75/ton)
Margin for wood (500 pounds) and manufacturing cost	64 ($256/ton of wood)

To manufacture such panels, bark-free, green, wood residues (coarse particles from dowel machines, for instance) are ring-flaked and blended with water, cement, and other chemicals in a horizontal drum with agitators. Air classifying heads form a graduated mat with a superfine surface. Mats (about 4 by 8 feet in size) are placed on steel cauls and stacked in a clamp-cradle closed under pressure. The clamp-cradle is then removed from the cold press and transported to a slightly heated curing chamber where it remains for 10 hours. The press is then employed a second time to permit removal of locking pins from the clamp-cradle. The partially cured panels are removed, trimmed to size, and further cured for 14 days at ambient temperature. Finally they are conditioned to 12 percent moisture content.

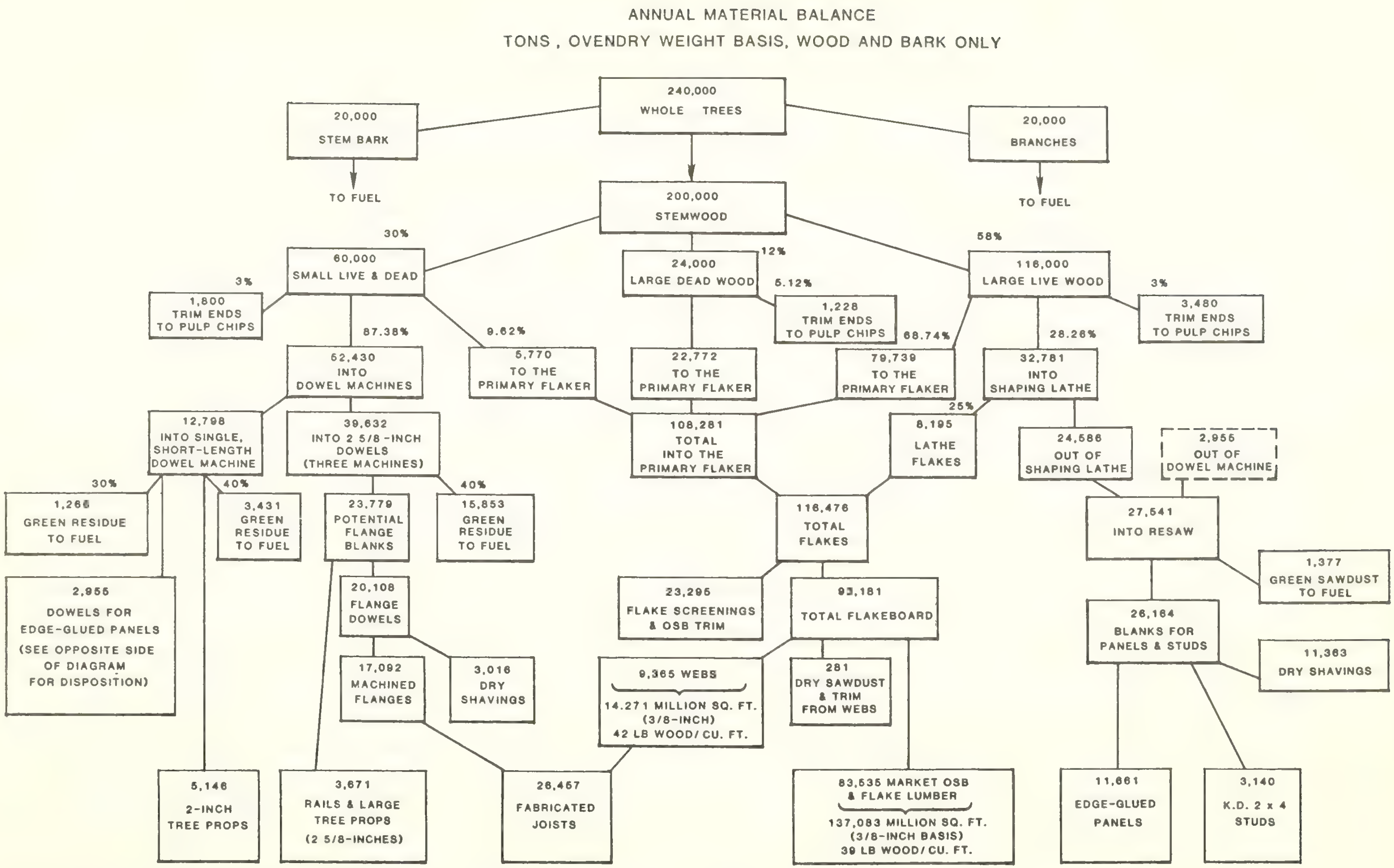


Figure 3-8—Wood and bark material balance based on annual tonnage (ovendry weight basis). Weights of resins and wax incorporated in the products are not included.

There is no established market in the Intermountain region for this type of panel, but an entrepreneur willing to establish a market might find that wood-cement composites are a potential end use for excess residues not salable as pulp chips or needed for fuel. If 25 million ft^2 of $^1/_2$-inch composite panel (41,668 tons, grossing $5 million) could be sold annually in the region, the wood component would total about 10,417 tons (ovendry) annually.

The product is not considered further here, but it appears to have some possibilities as a means to market excess green residues.

Oriented-Strand Board—Structural flakeboard plants in North America are increasingly manufacturing oriented-strand board (OSB) rather than waferboard with randomly oriented flakes. The major product manufactured is $^7/_{16}$-inch-thick sheathing for use under shingles or siding in residential construction (see chapter 9). Other OSB products include thicker panels for decking, and thinner decorative panels. Depending on the density of the parent wood, density of the panels is generally in the range from 37 to 45 lb/ft^3, ovendry weight basis; of this weight 3 to 4 percent is P/F resin and about 1 percent wax. For lodgepole pine OSB, an ovendry panel density of 41 lb/ft^3 should yield acceptable panel properties.

As noted later, a significant proportion (about 10 percent) of the output of the proposed flakeboard plant will be manufactured as webs for fabricated pole joists. These webs—to enhance inplane shear strength—will have random flake orientation and higher density than the market OSB.

In North America, plants manufacturing OSB typically range in size from 100 million to 300 million ft^2 annually ($^3/_8$-inch basis). Manufacturing economies of scale are significant. Midsize plants (150 to 160 million ft^2 annually) have perhaps $10 per thousand ft^2 lower costs than the smallest plants; the largest plants enjoy a similar cost advantage over the midsize plants. Wood supply in the Libby-Troy area probably limits panel production—when meshed with a multiproduct operation (fig. 3-8)—to about 150 million ft^2 annually, $^3/_8$-inch basis.

Oriented-Strand Lumber—Gradual liquidation of old-growth timber in North America, followed by replacement with smaller diameter trees, has resulted in scarcity of wide, long, high-quality structural lumber of uniform strength. Because of this scarcity it is probable that, within a decade or two, oriented-strand structural lumber will be a significant factor in the lumber market.

Already minor factors in the structural lumber market, parallel-laminated-veneer lumber and lumber laminated from long (>6 inches) veneer strands show promise of increasing market penetration. These high-performance products have modulus of elasticity (MOE) values near 2 million lb/in^2, and command prices near $1,000 per M bd ft.

It seems likely that oriented-strand lumber with somewhat lower MOE—perhaps 1.4 million lb/in^2—selling at a price competetive with upper structural grades of solid-sawn lumber (such as $240 per M bd ft), will emerge as a strong competitor in the market. Such lumber would be comprised of flakes only about 3 inches long (the same as for OSB) and could be made in the same presses as OSB—but with double or triple usual OSB resin content.

The usual OSB presses for a plant of the size contemplated have perhaps 16 openings with platens 8 feet wide, and 16 feet long. By equipping the proposed plant with an 8-opening press having 8-foot-wide platens 32 feet long (instead of 16 feet), and sufficient space between platens (daylight) to accommodate mats thick enough for $1^1/_2$-inch-thick panel products, the plant would be in a position to make fully oriented-strand lumber in lengths to 32 feet and widths specified by the customer.

Tree Props

Structural flakeboard can be made from most species of wood in North America, and lodgepole pine has no particular advantage over other low-density woods available. For a few specialized products, however, lodgepole pine has a significant advantage over other species. Because of its small diameter, superior stem form (little stem taper), high strength/weight ratio, small branch diameter, and lack of a weakening juvenile-wood core, lodgepole pine is unique in North America as a species adapted for manufacture of pith-centered structural dowels and small-diameter roundwood products.

During the last decade a significant market has been developed in the Southwest—particularly in California—for 6- to 12-foot-long pith-centered lodgepole pine dowels for use as tree props (fig. 3-1). The major demand is for props 2 inches in diameter and 8 or 10 feet long, although $1^1/_2$-inch props are also in demand. In addition to tree props sold to orchardists and landscapers, the agricultural industry consumes large numbers of doweled products such as stakes, posts, and rails of various dimensions in vineyards, hop fields, berry farms, and pastures. Idaho and Montana producers of these products have done an outstanding job of developing and expanding markets for these products in the Southwest, but none have made significant efforts to develop Midwest markets.

Stem sections suitable for 2-inch tree props measure about $2^1/_8$ to $2^1/_4$ inches in diameter inside bark at the small end, and about $2^3/_4$ inches at the large end; stem section lengths for this purpose are predominantly 96 or 120 inches long but may be as short as 72 inches and as long as 144 inches.

Doweling machines used in the industry can produce, under good conditions, about 2,200 tree props per 8-hour shift. If run three shifts, 350 days a year, a single machine should annually produce about 5,146 tons of 2-inch tree props (about 2 million pieces averaging 9 feet long) plus perhaps 2,955 tons (ovendry basis) of larger dowels. Residue from the dowel machine should total about 4,697 tons—in a form not suitable for sale as pulp chips, but usable in boilers capable of burning green fuel.

Fabricated Joists

There are many designs of joists available in the U.S. market. The dominant Northwest products in the wood-joist market, however, are probably machine-stress-rated

(MSR) kiln-dried 2 by 10's and 2 by 12's, and the $9^{1}/_{2}$-inch-deep and $11^{7}/_{8}$-inch-deep joists fabricated in Idaho and Oregon with laminated-veneer flanges and plywood webs. The solid lumber product is generally available in random lengths from 10 to 20 feet, while the fabricated joists are rail-shipped in 64-foot (or even 80-foot) lengths to distribution yards where they are cut to exact lengths according to each builder's needs; short lengths are cut into blocking needed to laterally stabilize the joists. Where uniformity of stiffness and strength are not critical, much kiln-dried 8/4 #2 fir and larch in 10- and 12-inch widths is also sold for joists.

Starting from the well-accepted premises that minimally machined cylindrical stemwood is significantly stronger and has higher MOE than sawn lumber of the same cross section (Doyle and Wilkinson 1969), and that structural flakeboard has high inplane shear strength (Chen and others 1989), a series of experiments were executed to develop fabricated joists utilizing minimally machined lodgepole pine stems as flanges and structural flakeboard as webs (Burke and Koch 1986; Burke and Koch 1987; Koch and Burke 1985; see also appendix III).

As originally conceived, two designs were described (Koch and Burke 1985). The first of these designs employed flanges made of dowels (more or less pith-centered) machined from whole stems. The second employed somewhat larger dowels center-split to yield a pair of flanges from a single stem; in cross section these joists have somewhat the shape of a stemmed wine glass. For a variety of reasons explained in Burke and Koch (1987), the second design was dropped in favor of the first (fig. 3-2).

The research program cited yielded products competitive to solid-sawn 2 by 10's and 2 by 12's. These fabricated pole joists (figs. 3-2 and 3-3) are lighter than most fir and larch lumber joists but heavier than the competitive fabricated joists with laminated-veneer flanges. They are, however, significantly stiffer (have greater EI) than these competitive products and have significantly higher maximum resistive moment (load carrying capacity in edgewise bending) at 100 percent of design load (table 3-3 and appendix III).

Because, in the United States, the specific gravity of lodgepole pine stemwood is positively correlated with latitude (Koch 1987, fig. 4-44), trees grown in northern Montana should have significantly higher mechanical properties than those grown farther south. This supposition was confirmed by tests of lodgepole pine stemwood sections in compression parallel to the grain; the tests showed that stemwood from small trees sampled in Montana had significantly higher MOE and ultimate

Table 3-3—Comparison of depth, weight, stiffness (EI), bending strength (design resistive moment), and maximum vertical shear (100 percent of design load) of proposed fabricated lodgepole pine pole joists with machine-stress-rated Douglas-fir and larch kiln-dried lumber, and with competitive Douglas-fir fabricated joists having laminated-veneer flanges and plywood webs

Property	MSR lumber 1.5E - 1650f	Competitive fabricated joists	Proposed fabricated joists (fig. 3-2)
2 by 10's			
Depth, inches	$9^{1}/_{4}$	$9^{1}/_{2}$	10
Weight/lineal foot at 10-percent moisture content, pounds	2.7	1.9	2.9
EI, million inch² pounds	148	[1]170	253
Maximum resistive moment at 100 percent of design load, foot pounds	2,938	[1]2,940	7,096
Maximum vertical shear at 100 percent of design load, pounds	902	805	946
2 by 12's			
Depth, inches	$11^{1}/_{4}$	$11^{7}/_{8}$	12
Weight per lineal foot at 10-percent moisture content, pounds	3.8	2.0	3.1
EI, million inch² pounds	267	285	387
Maximum resistive moment at 100 percent of design load, foot pounds	4,346	3,935	9,333
Maximum vertical shear at 100 percent of design load, pounds	1,068	990	1,000
2 by 14's			
Depth, inches	—	14	14
Weight per lineal foot at 10-percent moisture content, pounds	—	2.82	3.3
EI, million inch² pounds	—	550	516
Maximum resistive moment at 100 percent of design load, foot pounds	—	6,450	11,595
Maximum vertical shear at 100 percent of design load, pounds	—	1,160	1,000
2 by 16's			
Depth, inches	—	16	16
Weight per lineal foot at 10-percent moisture content, pounds	—	2.98	3.5
EI, million inch² pounds	—	745	636
Maximum resistive moment at 100 percent of design load, foot pounds	—	7,570	13,871
Maximum vertical shear at 100 percent of design load, pounds	—	1,315	1,000

[1]These are sales-bulletin values. Our destructive tests of five of these Douglas-fir joists indicated an EI of 127 million inch² pounds, and a value of 1,725 foot pounds for maximum resistive moment at 100 percent of design load in bending.

compressive strength than stemwood sampled from other States in the lodgepole pine range (Koch and Barger 1988). This phenomenon appears to give Montana operators an advantage over potential joist manufacturers in other States within the lodgepole pine range.

Doweling tests by Burke and Koch (1987) indicate that stem sections selected to be doweled for flanges should be 16 feet long, free of large bark inclusions and large knots, with sweep less than $1^1/4$ inches, and with spiral grain of less than 5 degrees. For dowels turned green to a diameter of $2^5/8$ inches for use as flanges, stem-section top diameter inside bark should be about 2.8 inches, with butt diameter averaging about 4.0 inches. These proportions will yield about 40 percent residues. In general, stem sections appropriate for flange dowels are found in whole stems just below the portions suitable for manufacture into tree props.

After kiln drying, flange dowels will be nondestructively tested for MOE, and those below the acceptable threshold (perhaps 15 percent if the lower threshold MOE for flanges at 10-percent moisture content is 1.5 million lb/in^2) will be marketed as rails or remanufactured into tree props.

Plant observations indicate that a single dowel machine can routinely produce about a thousand 16-foot-long dowels per 8-hour shift, that is, 16,000 lineal feet. If operated three shifts for 350 days per year (1,050 shifts - 50 maintenance shifts), a single dowel machine should produce about 16 million lineal feet per year.

Because 1 lineal foot of such a dowel $2^5/8$ inches in diameter has an ovendry weight of about one pound, annual output per machine should be about 16 million pounds or 8,000 tons of dowels.

Because production plans (fig. 3-8) call for 23,779 tons of flange dowels annually (ovendry-weight basis), three fully operational machines will be required. To obtain this tonnage of dowels, about 39,632 tons of stemwood will be admitted to the machines annually (fig. 3-8).

Of the 23,779 tons of candidate flange dowels, about 15 percent (3,671 tons annually) will be culled for rails and tree props as noted previously. From the acceptable kiln-dried dowels, about 15 percent of the weight will be removed in the form of shavings produced during finger-jointing and assembly to 64-foot lengths, dadoing a groove to receive the web, and machining the finished joist to prescribed dimensions (fig. 3-2). Thus about 17,092 tons (41.100 million lineal feet, sufficient for 20.550 million lineal feet of joists) will end as machined flanges. Also produced will be about 3,016 tons of dry shavings usable for fuel or salable as particleboard furnish.

About 9,365 tons (ovendry) of $^3/8$-inch flakeboard will be needed annually to assemble with the 17,092 tons of flanges. These computations are based on the assumption that sales of 2 by 12 fabricated joists will be double the lineal footage of 2 by 10 joists.

Edge-Glued Lumber Panels

The transition from large timber to smaller trees grown on short rotations has affected not only structural lumber markets, but also markets for millwork grades of lumber. With the passing of readily available old-growth, large-diameter ponderosa, eastern white, Idaho white, and sugar pines, the price of wide 5/4 through 10/4 millwork-grade pine lumber with small sound knots has risen significantly. In 1987, edge-glued panels of such wood were offered only at prices near $1,000 per M bd ft—and most market experts forecast increasing prices.

This shortage of millwork-grade wood of traditional species offers an opportunity to capitalize on the light color, soft texture, straight grain, lack of a large core of inferior juvenile wood, and attractive knot pattern of lodgepole pine. While edge-glued panels are commonly assembled from components rectangular in cross section, there is no technical reason why they cannot be assembled from boards trapezoidal in cross section (figs. 3-4 and 3-5) if board edges are suitably toothed to prevent slippage under edge pressure during glue assembly. Conversion of small-diameter logs into boards trapezoidal in cross section can be both rapid and efficient, with product yields as good or better than recoveries of square-edged boards from larger logs (fig. 3-4).

A log merchandising deck of the kind envisioned for the manufacturing operation under analysis permits selection of stem sections with desired knot structure before they are cut to prescribed length, and sorted into narrow diameter classes to maximize lumber yield. Typically, stem sections 100 inches long would be turned to cylindrical form on a shaping lathe (fig. 3-9) to yield flakes for OSB as a residue. The cylinders would then be center-ripped, with or without recovery of a pith-centered board, kiln-dried, face-jointed on the sawn surface, and moulded to trapezoidal shape (fig. 3-4) prior to assembly into panels (fig. 3-5).

Machine observations indicate that a single 100-inch shaping lathe can turn about 1,680 100-inch-long stem sections into cylinders per 8-hour shift. If the bark-free stem sections have average small-end diameter of 5 inches, and large-end diameter of $5^3/4$ inches, and the lathe operates three shifts per day for 350 days per year less 50 maintenance shifts annually (to match operating days of the OSB plant), annual input to the shaping lathe should be about 32,781 tons of stemwood (ovendry-weight basis), and output of cylinders will be about 75 percent of this tonnage, or 24,586 tons—assuming bolts are selected for roundness and straightness. Flake output from the lathe should therefore be about 8,195 tons.

Because small-diameter bolts are better suited to a doweling machine, about 2,955 tons (ovendry basis) of such smaller dowels will supplement those from the shaping lathe to yield a total of 27,541 tons admitted to the resaw at the beginning of the process to manufacture edge-glued panels (fig. 3-8).

Yield of edge-glued panels (11,661 tons) and studs (3,140 tons) should comprise about 54 percent of the weight of the cylinders and dowels admitted to the resaw (ovendry-weight basis). The ovendry-weight yield of edge-glued panels and studs from the bark-free bolts entering the process (selected for diameter, knot structure, straightness, and roundness) should be about 40 percent.

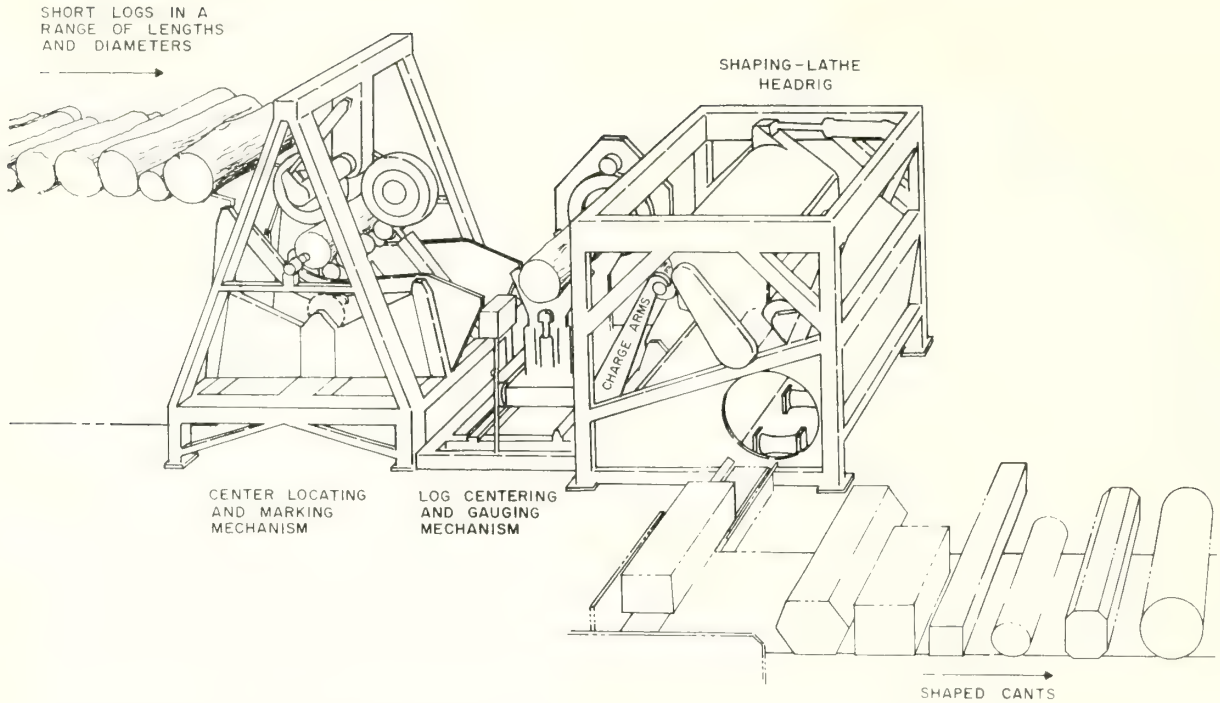


Figure 3-9—Shaping lathe headrig designed to produce cylinders or polygons of various dimensions. For the application described in the text, all logs would measure 100 inches long and would be machined into cylinders. Machine residue is in the form of flakes suitable for OSB. (Drawing after Koch 1985, p. 1921.)

3-3 MATERIAL BALANCES

With annual plant input of 200,000 tons of stemwood (ovendry-weight basis), and tree props, rails, fabricated pole joists, edge-glued lumber panels, and studs produced in the tonnages described in the foregoing paragraphs (fig. 3-8), output of structural flakeboard should be about 93,181 tons—9,646 tons used annually for webs in fabricated joists, (including dry sawdust and trim from webs), and the balance (83,535 tons) sold as market OSB. As noted earlier, the web material will have random flake orientation and be denser than the market OSB. On a $^3/_8$-inch-thickness basis, total annual flakeboard output will be about 151 million ft^2 (fig. 3-8).

Residues from plant operations should be about as follows (fig. 3-8):

Residue description	Annual production	
	Tons, ovendry basis	
Salable		
Pulp chips	6,508	
Dry shavings	14,379	
		20,887
Fuel for plant consumption		
Dry flake screenings and trim	23,576	
Bark	20,000	
Green hog fuel	41,927	
		85,503
Total residues		106,390

Annual output (wood-content weight, and other measures) of salable products—excluding pulp chips and other residues—should be about as follows (fig. 3-8):

Product	Wood content, ovendry	Market measure
	Tons	
2-inch tree props	5,146	2 million pieces averaging 9 feet in length
$2^5/_8$-inch tree props and rails	3,671	520,000 pieces averaging 14 feet long
Fabricated joists	26,457	6,850,000 lineal feet of 10-inch joists and 13,700,000 lineal feet of 12-inch joists
Edge-glued panels	11,661	6,500,000 ft^2 averaging $1^1/_2$ inches in thickness
2 by 4 studs	3,140	4 million bd ft
Market OSB	83,535	117,500,000 ft^2 of $^7/_{16}$-inch sheathing
Total	133,610	

3-4 SUMMARY

Based on an annual input of 200,000 tons of stemwood and 40,000 tons of stembark and branches (ovendry-weight basis), high-value products totaling 133,610 tons (67 percent of stemwood weight) should be produced. Of

the residual 106,390 tons of stemwood, bark, and branches, about 20,887 tons will be sold as pulp chips or particleboard furnish; the remainder will be burned as fuel to produce process heat for the plant.

Net plant-gate sales values represented by these tonnages total $38,194,000 (table 9-1).

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CHAPTER 4: PRODUCT PROPERTIES

CONTENTS

4-1 TREE PROPS

As noted in section 3-2, tree props (fig. 3-1) are generally sold in lengths of 6, 8, 10, or 12 feet; the principal market is for 8 and 10 footers. Two-inch-diameter props are predominant, but diameters may be as small as $1^1/2$ inches and as large as 3 inches. The props are machined to uniform diameter from small stems so that stem piths are more or less centered in cross section.

Of importance to users of tree props are the mechanical properties of modulus of elasticity (MOE), which is a determinant of stiffness of the prop, and strength in tension and compression, which are determinants of strength in bending. Also, the dry weight of the props (a function of the wood specific gravity) is of interest because light weight lowers freight cost and eases handling. Additionally, permeability is of interest because most tree props must be pressure treated with preservatives—usually CCA (chromated copper arsenate). Not least in importance is straightness when shipped, installed, and in service.

As reported by Koch (1987), lodgepole pine stemwood from trees of small diameter has significantly higher specific gravity and mechanical strength than stemwood of the larger trees on which "Wood Handbook" (USDA FS 1974) data were based (figs. 4-1 through 4-7).

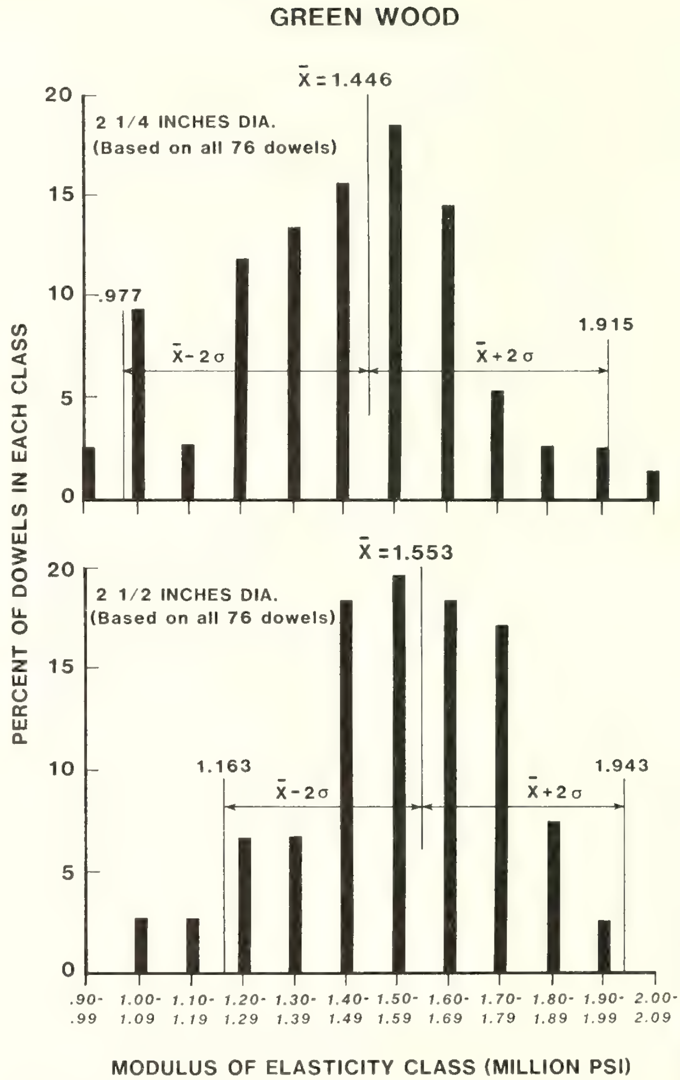

Figure 4-1—Distribution of values of modulus of elasticity at green moisture content for 2.25-inch- and 2.50-inch-diameter dowels machined from lodgepole pines sampled in the area from Libby to West Glacier in Montana.

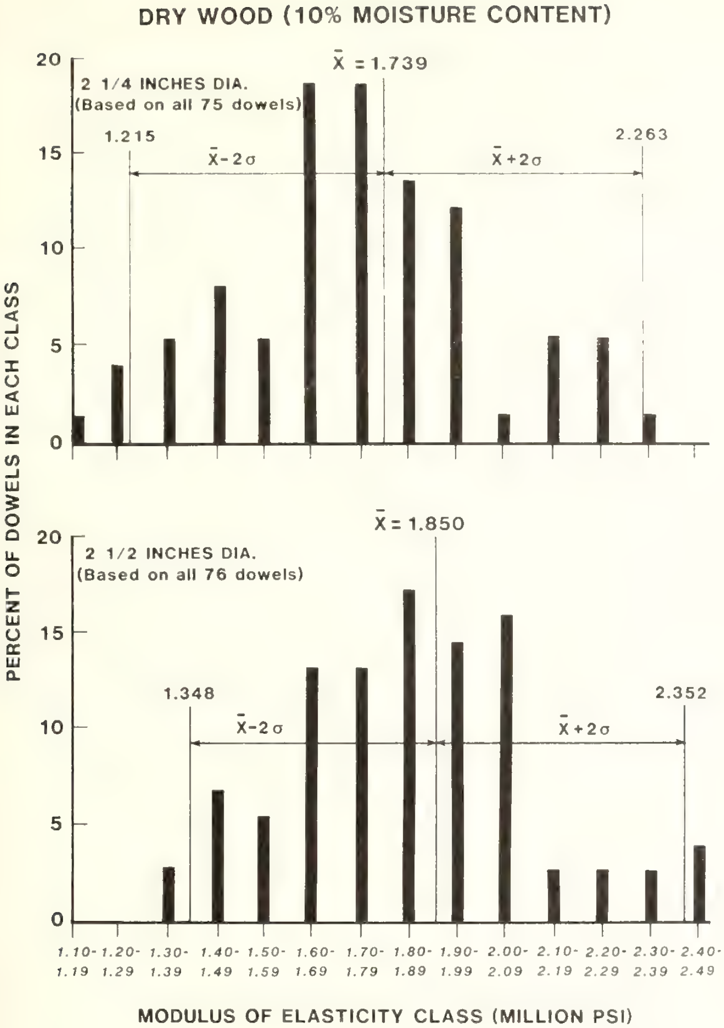

Figure 4-2—Distribution of values of modulus of elasticity at 10 percent moisture content for 2.25-inch- and 2.50-inch-diameter dowels machined from lodgepole pines sampled in the area from Libby to West Glacier, MT.

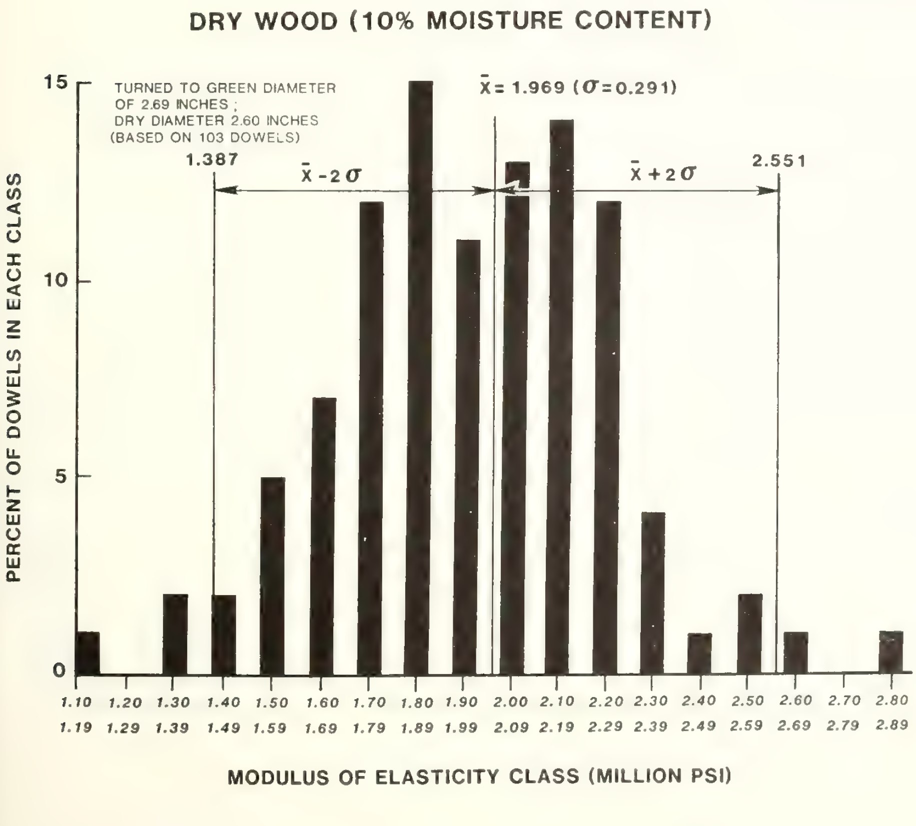

Figure 4-3—Distribution of values of modulus of elasticity at 10 percent moisture content for dowels turned green to a diameter of 2.69 inches. The dowels were turned from lodgepole pines sampled in the Miller Creek drainage about 25 miles east of Libby, MT.

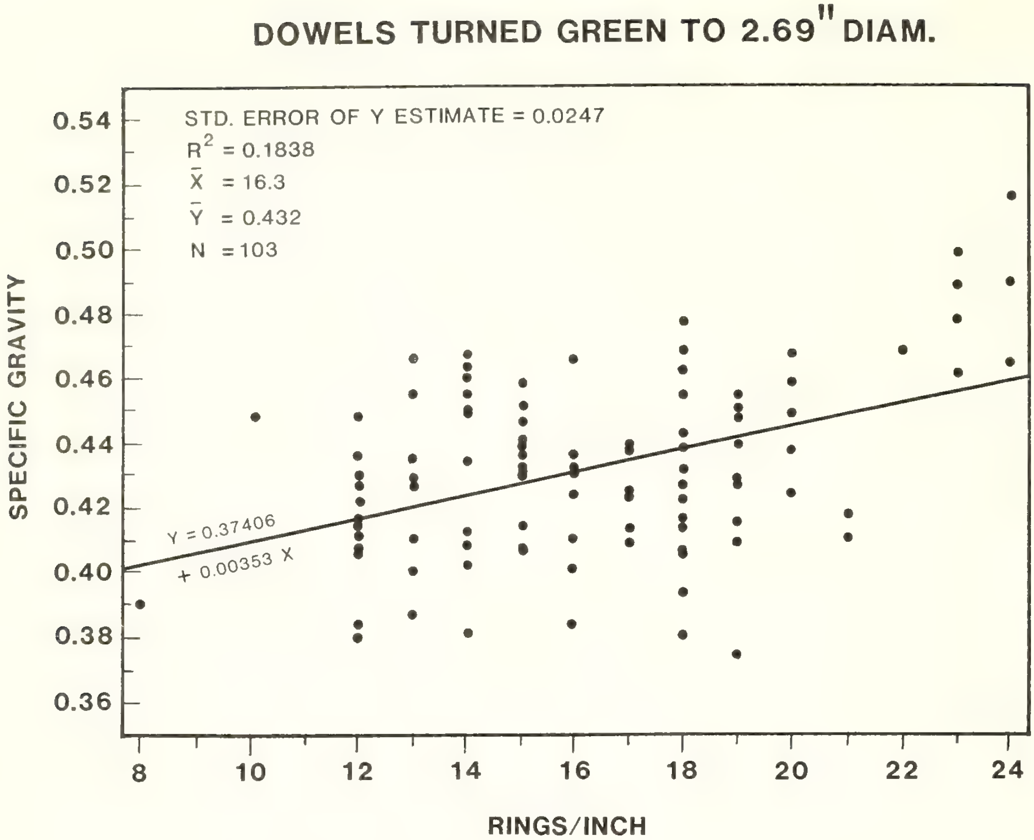

Figure 4-4—Rings per inch in dowel ends related to dowel specific gravity (based on ovendry weight and green volume). The lodgepole pines from which the dowels were machined were sampled in the Miller Creek drainage east of Libby and turned green to 2.69 inches in diameter.

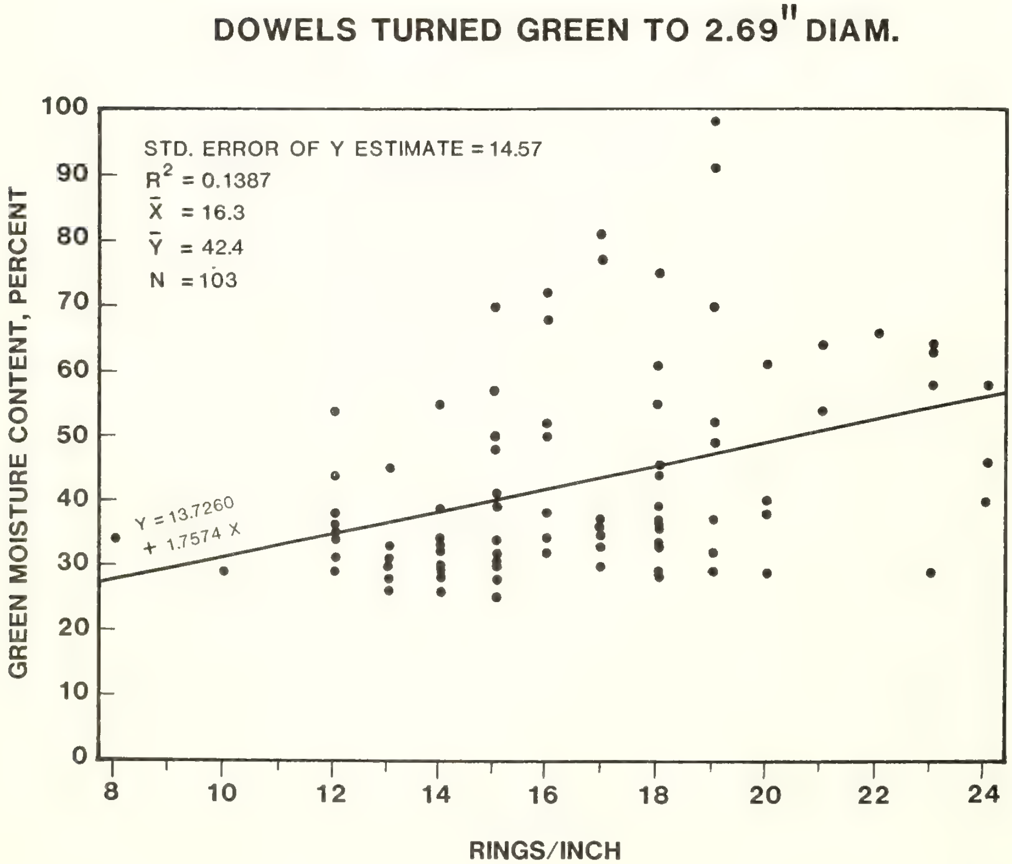

Figure 4-5—Moisture content (percentage of ovendry weight) of green 2.69-inch-diameter lodgepole pine dowels related to rings per inch in dowel ends. Trees from which the dowels were turned were cut in the Miller Creek drainage east of Libby, machined the next day in Missoula, MT, and the green moisture content determined in the laboratory the following day. Some water content was lost during the 50-mile transport from Missoula to the laboratory.

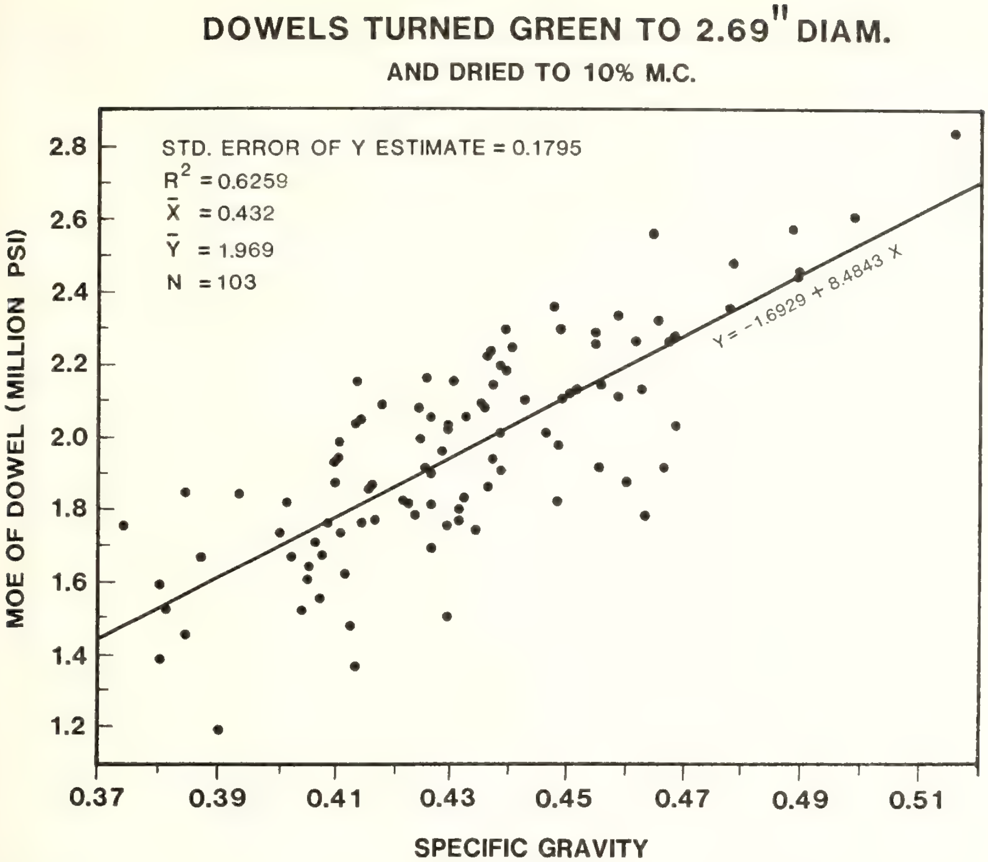

Figure 4-6—Modulus of elasticity of pith-centered lodgepole pine dowels (at 10 percent moisture content) from the Miller Creek drainage turned green to 2.69 inches in diameter related to dowel specific gravity (based on green volume and ovendry weight).

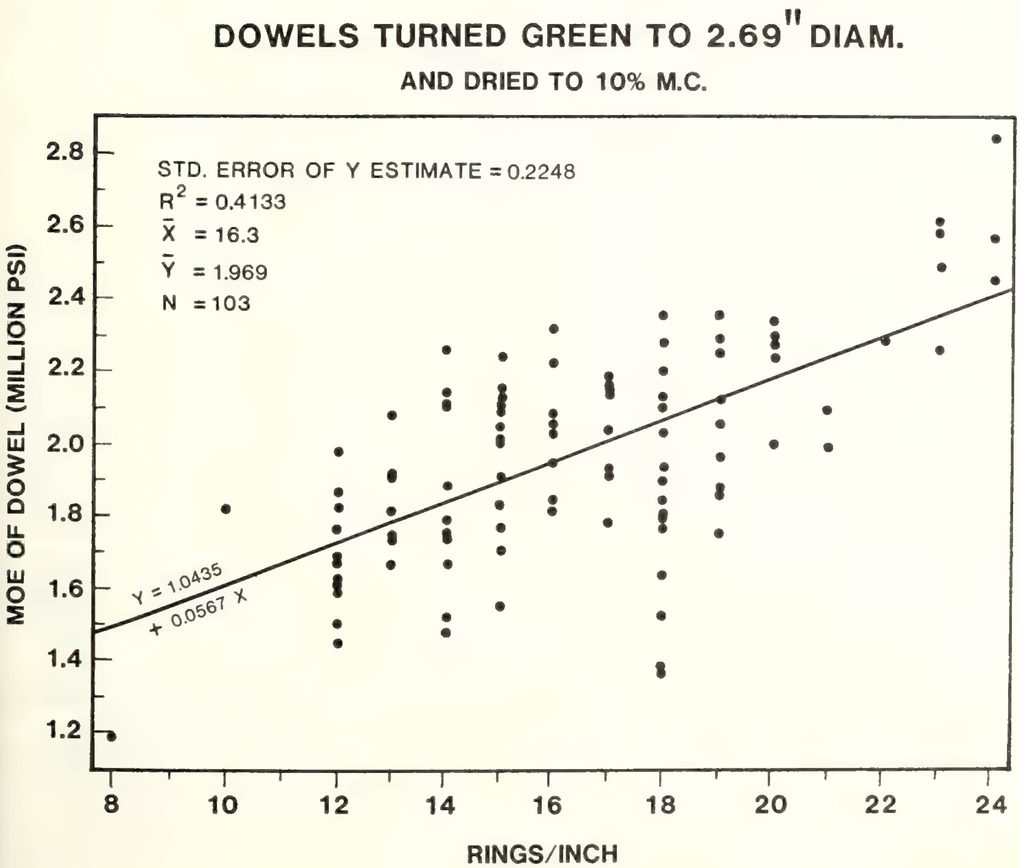

Figure 4-7—Modulus of elasticity of pith-centered lodgepole pine dowels (at 10 percent moisture content) from the Miller Creek drainage turned green to 2.69 inches in diameter related to the average number of rings per inch in the two dowel ends.

Specific Gravity

Throughout the full latitudinal range of lodgepole pine (var. *latifolia*) from 40 to 60 degrees, entire stemwood of trees measuring 3, 6, and 9 inches in diameter at breast height has specific gravity averaging 0.43, 0.42, and 0.41, respectively, based on ovendry weight and green volume. Specific gravity of such trees increases with increasing latitude from south to north up to the Canadian border, and is then more or less constant to 60 degrees (appendix fig. III-9; Koch 1987). Thus, lodgepole pines in Montana have near-maximum specific gravity for the species.

Ten lodgepole pine trees 4 to $4^1/2$ inches in d.b.h. sampled by Koch and Barger (1988) from the Kootenai, Flathead, Deerlodge, Gallatin, and Helena National Forests in Montana had average stemwood specific gravity of 0.492. This value was obtained from disks taken at 20 percent of tree weight—height at which specific gravity is close to the entire stemwood average—and is based on ovendry weight and volume at 8.2 percent moisture content.

Burke and Koch (1987) and Koch and Burke (1988) found that 16-foot-long dowels turned when green to diameters of $2^1/4$, $2^1/2$, and 2.69 inches had specific gravities of 0.42, 0.43, and 0.43, respectively (based on ovendry weight and green volume). Trees from which the $2^1/4$ and $2^1/2$-inch dowels were turned were sampled from three locations in the Libby to West Glacier area of northwestern Montana. Those turned 2.69 inches in diameter came from the Miller Creek drainage about 25 miles east of Libby, MT. Dowel properties are summarized as follows:

	Green dowel diameter, inches		
Statistic (average values)	**$1^1/4$**	**$2^1/2$**	**2.69**
Number of dowels evaluated	76	76	103
Specific gravity (based on ovendry weight and green volume)	0.42	0.43	0.43
Moisture content when green, percent of ovendry weight	61.9	58.4	42.4
Diameter shrinkage (green to about 10 percent moisture content), inch	0.10	0.10	0.09
Sweep in 16-foot lengths, inch			
When green	0.80	0.60	—
When at 10 percent moisture content	0.80	0.70	—
Modulus of elasticity measured in flexure over a 15-foot span with center-point loading, million lb/in²			
When green	1.446	1.553	—
When at 10-percent moisture content	1.739	1.850	1.969
Weight per lineal foot at 10-percent moisture content, pounds	0.78	0.98	1.17
Grain angle at dowel surface, degrees	1.40	1.50	2.3
Rings per inch	—	—	16

Stemwood specific gravity diminishes from stump height to treetop. For Montana lodgepole pines 3 to 9 inches in d.b.h. in the Libby-Troy latitude, stemwood values in the upper tree will likely average about 0.40 based on ovendry weight and green volume; at stump height the average will be near 0.47 (appendix figs. III-10 and III-11; Koch 1987).

Dowel specific gravity is positively correlated with rings per inch averaged from both dowel ends (fig. 4-4).

Moisture Content

Dowel moisture content is positively correlated with dowel rings per inch (fig. 4-5). Because heartwood content of dowels is high, moisture content is relatively low.

Modulus of Elasticity

These dowels turned from trees sampled in the Libby to West Glacier area and in the Miller Creek drainage of northwestern Montana had average modulus of elasticity values (nondestructively evaluated in flexure over a 15-foot span with center-point loading) as shown in the foregoing tabulation, with distribution of values as depicted in figures 4-1, 4-2, and 4-3. The standard deviations and ranges were as follows:

Dowel green diameter, inches and moisture content at test	Standard deviation	Range
	Million lb/in²	
$2^1/4$ inches		
Green	0.235	0.937-2.026
10 percent of ovendry weight	.262	1.136-2.376
$2^1/2$ inches		
Green	.195	1.081-1.985
10 percent of ovendry weight	.251	1.322-2.460
2.69 inches		
10 percent of ovendry weight	.291	1.193-2.841

Analysis of the 2.69-inch dowels from Miller Creek indicated that MOE was unrelated to dowel diameter shrinkage between green and dry, or to the grain angle of checks visible in dry dowel surfaces. MOE was, however, positively correlated with dowel specific gravity (fig. 4-6), and with rings per inch averaged from both ends of each dowel (fig. 4-7).

Only five of the 103 Miller Creek dowels turned green to 2.69 inches in diameter had MOE values of less than 1.5 million lb/in² (fig. 4-3). Of the 98 dowels with MOE values of 1.5 million lb/in² or greater, only six had defects (catfaces, large knots, bark inclusions, machine gouges) severe enough to eliminate them from use as joist flanges or other demanding structural use.

Unmachined stem sections have significantly higher MOE than those from which one-fourth or one-half inch of radius has been machined (appendix section III-4; fig. III-3).

Trends in MOE of stemwood from throughout the range of lodgepole pine in North America are discussed in appendix section III-6; in brief, there is a positive correlation between latitude and MOE.

Compression Strength

As with MOE, compression strength parallel to the grain of unmachined stem sections is slightly greater than in sections from which one-fourth or one-half inch of radius has been turned (appendix section III-4 and fig. III-4; Burke and Koch 1986). Therefore, data useful in predicting mechanical properties of dowels must be determined after they have been machined to diameter.

With this in mind, 10 lodgepole pines 4 to $4^1/2$ inches in d.b.h. were sampled from five National Forests in Montana; from each tree, stemwood sections (9 inches long taken to include a knot cluster) were removed at 20 percent of tree height. After drying, but prior to test, the stemwood sections were machined to cylindrical form $2^1/4$ inches in diameter. Properties of these sections in compression parallel to the grain, adjusted to 10-percent moisture content, were as follows:

	Compressive strength		
Statistic	Ultimate	Proportional limit	MOE
	Lb/in²		*Million lb/in²*
Average	7,116	4,928	1.629
Standard deviation	1,048	798	.256
Range	5,910-8,730	3,500-6,080	1.350-2.090

The probability is 95 percent that at least 95 percent of the distribution from which these compression specimens were taken will have an ultimate compression strength parallel to the grain in excess of 4,065 lb/in².

Tensile Strength

For a discussion of the variation in lodgepole pine stemwood tensile strength throughout the North American range of the species, see appendix section III-6.

In brief summary, ultimate tensile strength of pith-centered dowels turned from trees 3 inches in d.b.h. was positively correlated with latitude; when tested at 12 percent moisture content these dowels $2^1/4$ inches in diameter—and containing knot clusters—had average ultimate tensile strength of 5,158 lb/in².

Straightness

Stems of lodgepole pine from Montana forests are straighter than those of most conifers. When doweled, the sweep in 16-foot lengths will probably average about 0.7 inch when green, with range up to 2.5 inches and standard deviation of 0.4 inch. When dried to 10 percent moisture content, the dowels will probably have average sweep of 0.7 inch, with standard deviation of 0.3 inch and range up to about 2 inches. Sweep will be slightly less in large-diameter than in small-diameter dowels.

Permeability

Because tree props are imbedded in the ground during use, they are usually treated with preservatives to inhibit decay. One of the most useful indicators of the treatability of wood with liquid preservatives is permeability by gas.

Hofmann (1986) examined the gas permeability of lodgepole pine stemwood specimens sampled from throughout the major latitudinal and longitudinal range of the species. The specimens—both heartwood and sapwood—were taken from about 10 percent of tree height and evaluated when at a moisture content of 13 percent of ovendry weight. Hofmann's measurements showed that the sapwood of lodgepole pine has permeability corresponding to the lower third of the permeability range for southern pine (an easily treated species), indicating a reasonably good treatability of the wood with liquids. Unlike southern pine, however, lodgepole pine has a fairly high heartwood content—especially in trees of small diameter. Since the heartwood of lodgepole pine is approximately 10 times less permeable than its sapwood, tree props comprised mostly of heartwood are difficult to impregnate with liquid preservatives. Permeability of sapwood and heartwood were unrelated to elevational zone, latitude, or longitude—except as these factors influenced the proportion of heartwood in the specimens. Trees 3 inches in d.b.h. had heartwood that was more permeable and sapwood that was less permeable than comparable tissues in trees 6 and 9 inches in d.b.h.

In spite of the impermeability of its heartwood, lodgepole pine tree props are favored in the market because of their strength, straightness, and light weight. For use in some adverse climates, however, it would be wise to incise props comprised mostly of heartwood, thereby increasing preservative penetration and retention.

Summary Statistics on Miller Creek Dowels

To conclude this section on dowel properties, following are some summary statistics on 103 16-foot-long pith-centered dowels from lodgepole pines sampled about 25 miles east of Libby, MT, from the Miller Creek drainage. These dowels were turned green to 2.69 inches in diameter and air dried to 10.17 percent moisture content (range 9.09 to 11.25 percent).

Property	Average	Standard deviation	Range
Moisture content when green, percent	42.4	15.5	25-98
Specific gravity based on ovendry weight and green volume	0.432	0.027	0.374-0.515
Weight per lineal foot when ovendry, pounds	1.07	0.07	0.91-1.28
Rings per inch	16.3	3.3	8-24
Maximum grain angle evident from drying checks, degrees	2.3	1.6	0-7
Diameter when air dry, inches	2.60	0.01	2.56-2.63
Diameter shrinkage from green to air dry, inch	0.09	0.01	0.07-0.12
Modulus of elasticity, million lb/in²	1.969	0.291	1.193-2.841

4-2 FABRICATED JOISTS

Properties of the joists (fig. 3-2) are compared to those of competitive products in table 3-3, and summarized from appendix section III-12 as follows:

Property	Fabricated joist depth (fig. 3-2)			
	10 inches	12 inches	14 inches	16 inches
Depth, inches	10	12	14	16
Weight per lineal foot at 10-percent moisture content, pounds	2.9	3.1	3.3	3.5
EI, million inch² pounds	253	387	516	636
Maximum resistive moment at 100 percent of design load, foot pounds	7,096	9,333	11,595	13,871
Maximum vertical shear load at 100 percent of design load, pounds	946	1,000	1,000	1,000

The correlation between the modulus of elasticity of the dry dowels used to make the flanges and the EI of the joists (appendix fig. III-17) is not particularly strong (R^2 = approximately 0.5); that is, only about 50 percent of the variation in EI of the joists (EI is a measure of joist stiffness) is explained by the modulus of elasticity of the dry dowels used as flanges in the joists. Tests comparing the modulus of elasticity of the flange dowels before and after machining the slot for the web and flats on three sides (appendix fig. III-16 and appendix table III-5) suggest that this machining significantly reduces flange modulus of elasticity and probably accounts for the poor correlation observed.

The correlation between the modulus of elasticity of the dry dowels and the ultimate resistive moment of the joists (a measure of load carrying capacity) is weak (R^2 = approximately 0.2); that is, only about 20 percent of the variation in ultimate resistive moment of the joists is explained by the modulus of elasticity of the dry dowels used as flanges in the joists (appendix fig. 111-18).

Both EI of the joists and ultimate resistive moment of the joists are poorly correlated with visual grade of the dowels used as flanges for the joists. Apparently bark inclusions, drying checks, and even moderately coarse knot clusters in the flange dowels do not have a powerful negative effect on EI and ultimate resistive moment of the joists. For this reason, the finger joints in the flanges—if well made—should not strongly affect the mechanical properties of the joists.

More important is the quality of the web and of the glue joint between flanges and web; interlaminar web shear adjacent to these joints is one of the major failure modes of the joists (appendix fig. III-21; appendix table III-8). When flanges break (rather than the web), the failures are sometimes in compression, but more frequently in tension.

Appendix III traces development of the pole joist and gives additional data on the physical and mechanical properties of such joists.

4-3 EDGE-GLUED LUMBER PANELS

As noted in section 3-2, the edge-glued panels (fig. 3-5) will be manufactured in a range of thicknesses (3/4 inch through 2 1/2 inches), lengths up to 96 inches, and widths up to 48 inches. Only wood with sound, small knots will be incorporated in the panels. Panels will be sanded on both sides and cut to size as required by the market.

The panels are intended for decorative woodwork, rather than for structural applications, so—while they will have the good mechanical properties consonant with their specific gravity of about 0.43 based on ovendry weight and green volume—strength is not of primary importance. Attractive appearance when given natural finishes, good machinability, and acceptable dimensional stability are the primary requisites of the panels.

Lodgepole pine machines readily and lacks the large, difficult-to-machine knots characteristic of some of the other pines used for millwork. The panels will be shipped at a moisture content (8 percent of ovendry weight) calculated to be about equal to that they will attain in service, thereby reducing problems from transverse shrinkage.

Wiedenbeck (1988) measured the shrinkage characteristics of stemwood—at 10 percent of tree height—from the 243 *latifolia* trees collected by Koch (1987) from 40 through 60 degrees latitude in North America. She found that specific gravity (based on ovendry weight and green volume) was linearly related to radial and tangential shrinkage from green moisture content to ovendry according to the following relationships:

Radial shrinkage in mixed sapwood and heartwood, percent $= 11.952G - 0.140$

Tangential shrinkage, percent $= 4.310G + 5.902$

The foregoing equations accounted for 46.6 percent of the variations observed in radial shrinkage, but only 3.7 percent of the variations observed in tangential shrinkage.

These relationships suggest that at a specific gravity of 0.43, radial shrinkage across mixed heartwood and sapwood will average about 5.00 percent, while tangential shrinkage of sapwood will average about 7.76 percent. Because of the nature of construction of the edge-glued panels (fig. 3-5), their width shrinkage should be intermediate between these two values, that is, about 6.4 percent from green to ovendry. Therefore, width shrinkage of these panels should be about 0.25 percent for each change of 1 percent moisture content from that at which shipped. For example, a panel measuring 10.0 inches wide when shipped at 8 percent moisture content will expand to about 10.025 inches in width if placed in service at 9 percent moisture content, and to about 10.100 inches if placed in service at 12 percent moisture content. Conversely it will shrink to 9.950 inches in width if in service at 6 percent moisture content.

Shipping weight should be about 31 lb/ft³.

4-4 ORIENTED-STRAND BOARD

The major portion of the wood content of the OSB panels will be lodgepole pine and a lesser portion other species, principally Douglas-fir, larch, and subalpine fir

(section 5-8 and table 5-1). The board will have an ovendry weight of about 41 lb/ft^3 and a shipping weight (at 8 percent moisture content) of about 44.2 lb/ft^3.

Flakes in panel faces will be aligned at 90 degrees to core flakes (fig. 3-6). Flakes cut 3 inches long with target thickness of 0.020 inch—after removal of extreme fines for fuel—will be screened so that the narrower flakes will be in the core and the wider flakes in the face layers (fig. 5-11).

With about 5 percent content of phenol-formaldehyde resin and wax, and moisture content at test of about 8 percent, the OSB in sheathing thickness (7/16-inch) should have mechanical properties about as follows:

Property	Direction of test: Parallel to face flake alignment	Direction of test: Across face flake alignment
	Lb/in²	
Modulus of elasticity	1,200,000	300,000
Modulus of rupture	7,000	3,000
Internal bond strength	90	

Quality control will ensure that the OSB products manufactured meet the American Plywood Association (1980) performance standards for sheathing and for combination subfloor and underlayment.

Flakeboard for Webs in Fabricated Joists

The flakeboard produced for internal consumption as webs in fabricated pole joists will not be OSB, but will have random orientation of flakes in all layers. Such random arrangement enhances in-plane shear strength of the webs. Also, the web flakeboard will be somewhat denser than the OSB sheathing product. Additionally, special emphasis will be placed on tightly bonding face flakes in these webs to enhance interlaminar shear strength adjacent to the web-flange joint.

4-5 ORIENTED-STRAND LUMBER

As noted in sections 3-2 and 5-8, the forming heads preceding the hot press (figs. 5-11 and 5-12) will be designed to permit mat formation with all flakes in all layers parallel to the 32-foot length of the press, thus permitting manufacture of 32-foot-long, 1.5-inch-thick, oriented-strand structural lumber from the same flakes utilized in the manufacture of OSB sheathing and floor panels.

The technology of making structural lumber from such flakes is in the early stages of development, but it seems likely that it will soon become practical to manufacture 1.5-inch-thick oriented flake composite (wood and adhesive) lumber with property values—at 10 percent moisture content—as follows (at a specific gravity of not more than 0.67 based on ovendry weight and volume at 10 percent moisture content):

Property	Average	Standard deviation	Range
	Lb/in²		
Modulus of elasticity	1,400,000	180,000	1,000,000-1,800,000
Modulus of rupture in edgewise bending	7,600	1,000	5,000-10,000
Compression parallel to the grain; that is crushing strength	5,250	400	4,250-6,250
Tensile strength parallel to the grain	3,500	400	2,500-4,500

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CHAPTER 5: PLANT LAYOUT, POWER, AND STAFFING REQUIREMENTS

CONTENTS

5-1 CHARACTERISTICS OF INCOMING WOOD

The plant (fig. 3-8; section 2-6) must receive, store, and process annually 240,000 tons of trees and logs—predominantly lodgepole pine—yielding 200,000 tons of stemwood, 20,000 tons of stembark, and 20,000 tons of branches (ovendry-weight basis). As discussed in section 3-3, products shipped will total 133,610 tons annually (wood content only, ovendry-weight basis) and will include tree props, fabricated joists, oriented-strand board and possibly oriented-strand lumber, edge-glued panels, 2 by 4 studs, pulp chips, and particleboard furnish; additionally, about 85,503 tons of residue for internal use as fuel will be generated annually during manufacturing operations (ovendry-weight basis).

Trees received at the plant will enter in two forms. The major portion of the wood entering the plant (yielding 110,000 tons, dry basis, of stemwood annually) will be in the form of whole, predominantly sub-sawlog-size lodgepole pine trees from National Forest lands. As much as one-fifth of this incoming tonnage, but probably a lesser proportion, will be from dead trees. All of these trees, both live and dead, will be severed at stump height and trucked, with branches attached, to the plant. Mixed in with the lodgepole pine trees will be some trees—probably 5 to 10 percent by weight—of other species, mostly Douglas-fir, larch, spruce, and subalpine fir. Butt diameters of the lodgepole pine trees will measure not less than 3 inches outside bark; an occasional tree might exceed 24 inches at the butt, but only about 4 percent will exceed 14.9 inches in breast-height diameter. About 90 percent of these trees from National Forest lands will have breast-height diameters in the range from 3.0 to 7.9 inches (table 2-4). Lodgepole pine stem lengths from stump top to apical tip and to a 2-inch top diameter inside bark, and average branch diameters should be about as follows (table 2-5):

Tree d.b.h.	Stem length to apical tip	Stem length to 2-inch top	Average branch diameter near stem
Inches	- - - - - *Feet*	- - - - -	*Inches*
3	30.5	16.5	0.35
6	51.2	39.1	.51
9	62.5	52.9	.75

A lesser amount of wood (yielding 90,000 tons annually of stemwood, ovendry-weight basis) will enter the plant in the form of tree-length logs of various coniferous species purchased on the open log market. Lodgepole pine logs will predominate, but significant proportions of Douglas-fir, larch, spruce, and subalpine fir will be included. Minimum top diameter inside bark will be 4.5 inches; butt diameters will be specified not to exceed 16 inches. Average butt diameter will probably be about 10 inches. Only logs cut from live trees will be accepted.

Regardless of wood source, no tree or log admitted to the plant will exceed 50 feet in length (generally they will be less than 40 feet), and none will be shorter than 8 feet.

Numbers of Trees Processed Annually

From National Forest Lands—The ovendry weight of stemwood from stump top to apical tip averages 20.2, 130.4, and 339.7 pounds for North American lodgepole pine trees measuring 3, 6, and 9 inches in d.b.h. (Koch 1987). From these data it can be inferred that trees 4, 6, and 8 inches in d.b.h. should have stemwood weights of about 43, 130, and 250 pounds, ovendry-weight basis.

From table 2-4, and the foregoing discussion, it is concluded that almost all the lodgepole pines to be drawn from the National Forest lands are in the 4-, 6-, and 8-inch diameter classes, in approximately the following proportions by numbers of trees:

D.b.h. class	Numbers of trees in Flathead, Lincoln, and Sanders Counties	Ratio (fraction) compared to d.b.h. class of 4 inches
Inches		
4 (3.0-4.9)	169,747,337	1.000
6 (5.0-6.9)	146,699,540	.373
8 (7.0-8.9)	77,307,764	.196
Total	393,754,641	

As 110,000 tons of stemwood, ovendry, will be harvested as whole trees from National Forest lands annually, it is possible to use the foregoing data to solve for the number of stems in the 4-, 6-, and 8-inch diameter classes comprising this 110,000 tons, as follows (where N = the number of 4-inch-class stems):

$$(110{,}000)(2{,}000 \text{ pounds}) = 43N + 130(0.373N) + 250(0.196N)$$

It follows, therefore, that the 110,000 tons of stemwood (predominantly lodgepole pine) harvested annually as whole trees from National Forest lands will be comprised as follows:

Tree d.b.h. class	Number of trees annually
Inches	
4	1,565,948
6	584,099
8	306,925
Total	2,456,972

Purchased on the Open Log Market—If the 90,000 tons of stemwood (ovendry basis) purchased annually on the open log market were specified to have a minimum top diameter of 4.5 inches inside bark and the average butt diameter was 10 inches, with inside-bark taper of 1.25 inches per 100 inches of stem length, average log length should be about 37 feet. Stemwood volume per log would therefore average about 10.6 ft^3, and ovendry stemwood weight should be about 300 pounds per log.

These data suggest that the component of wood purchased on the open log market should total about 600,000 logs annually.

5-2 SCALING, STORAGE, AND RETRIEVAL OF INCOMING WOOD

As previously noted, annual intake of wood will consist of about 2,456,972 whole trees cut from National Forest land (mostly 3 to 9 inches in diameter at the butt), and about 600,000 purchased logs (with top diameter of $4^1/_2$ inches and butt diameters averaging 10 inches and not exceeding 16 inches). These 3,056,972 trees and logs will be random length from 8 to 50 feet, but most will measure less than 40 feet in length.

Scaling

All incoming truckloads of whole trees and logs will be green-weight scaled, with payment based on estimated load content of ovendry stemwood weight.

Storage of Trees and Logs

Trucks will be unloaded with a portal crane (figs. 5-1 and 5-2). Offloaded whole trees and logs will be stacked separately in high decks under the portal crane. To the extent possible, the whole trees will be separated under the crane into piles of live lodgepole pine, dead lodgepole pine, and live trees of other species. The decks will be of sufficient capacity to store trees and logs adequate for 80 days of plant operation. A spray system designed to water-wet the decks during summer will be provided to suppress growth of blue-stain fungi in the stored wood.

The portal crane will move wood from storage to the infeed decks of the delimbers and debarkers. Whenever possible, however, the infeed decks will be served directly from incoming trucks.

Lodgepole pine logs and whole trees harvested in the Libby-Troy area should have moisture contents near the average (about 100 percent of ovendry weight) for the species in North America (Koch 1987, figs. 2-3 and 2-12). The annual intake of 240,000 tons of wood and bark (ovendry basis) is therefore equivalent to about 480,000 tons on a green basis.

If incoming trucks average 26 tons of green wood and bark per load, it follows that the portal crane must annually unload about 18,462 trucks. If wood is received 50 weeks per year, 369 trucks must be unloaded weekly. More likely, wood receivals will be restricted because of weather or road conditions to about 40 weeks per year, necessitating an average of 462 trucks weekly during the 40 operating weeks. If weight scaling and offloading are restricted to two 8-hour shifts 5 days per week during

each of the 40 operating weeks, about 46 loads must be offloaded per shift.

The green weight of purchased logs (wood plus bark) will average about 660 pounds each. The whole trees harvested from National Forest lands will have average green weight (wood plus bark and some foliage) of about 215 pounds each. On average, each truckload will therefore contain about 79 tree-length logs purchased on the open market, or about 215 whole trees of small diameter harvested from National Forest lands.

If 26-ton truckloads of incoming wood average 8 feet wide by 10 feet high, with maximum tree or log length of 50 feet, then an 80-day supply of wood (4,046 truckloads) will occupy decks 50 feet wide, 50 feet high, and 6,474 feet long. With main span of 165 feet, and 60 feet of cantilevered span on both ends, a total of five decks can be built (three under the main span—the center one arranged with stems parallel to the crane tracks, and one under each cantilevered end); thus the length of the craneway for storage purposes (not including space for offloading trucks, some log sorting, and space for infeed log decks feeding the delimber and debarker) should be about 1,295 feet long. To provide space for truck offloading, and for infeed decks (plus a little surplus storage), the proposed craneway is 1,500 feet long (fig. 5-2). In these decks, butts of logs and trees in each grapple load will all be oriented in one direction; brow logs strategically placed by the crane-grapple operator will facilitate this arrangement.

A crane-grapple payload capacity of 20 tons will permit quick loading of infeed decks, and will permit unloading of each log truck in two lifts. Available lift height under the grapple will be 55 feet, with lift speed of 50 ft/min, trolley speed (transverse to tracks) of 350 ft/min, and traverse speed along the crane tracks of 500 ft/min.

Connected power on the portal crane will total 340 hp: 150 hp on the hoist, two 15-hp motors on the trolley, two 50-hp motors to traverse the crane, and one 60-hp motor on the grapple.

The trolley and girder will have lights for night operation.

Figure 5-1—Portal crane with 20-ton lift capacity capable of offloading a log truck in two lifts. In the proposed plant the main span will be 165 feet and the two cantilevered end spans will each measure 60 feet. Clearance under the grapple will permit log storage to 50 feet high. (Photo from Harnischfeger Corporation.)

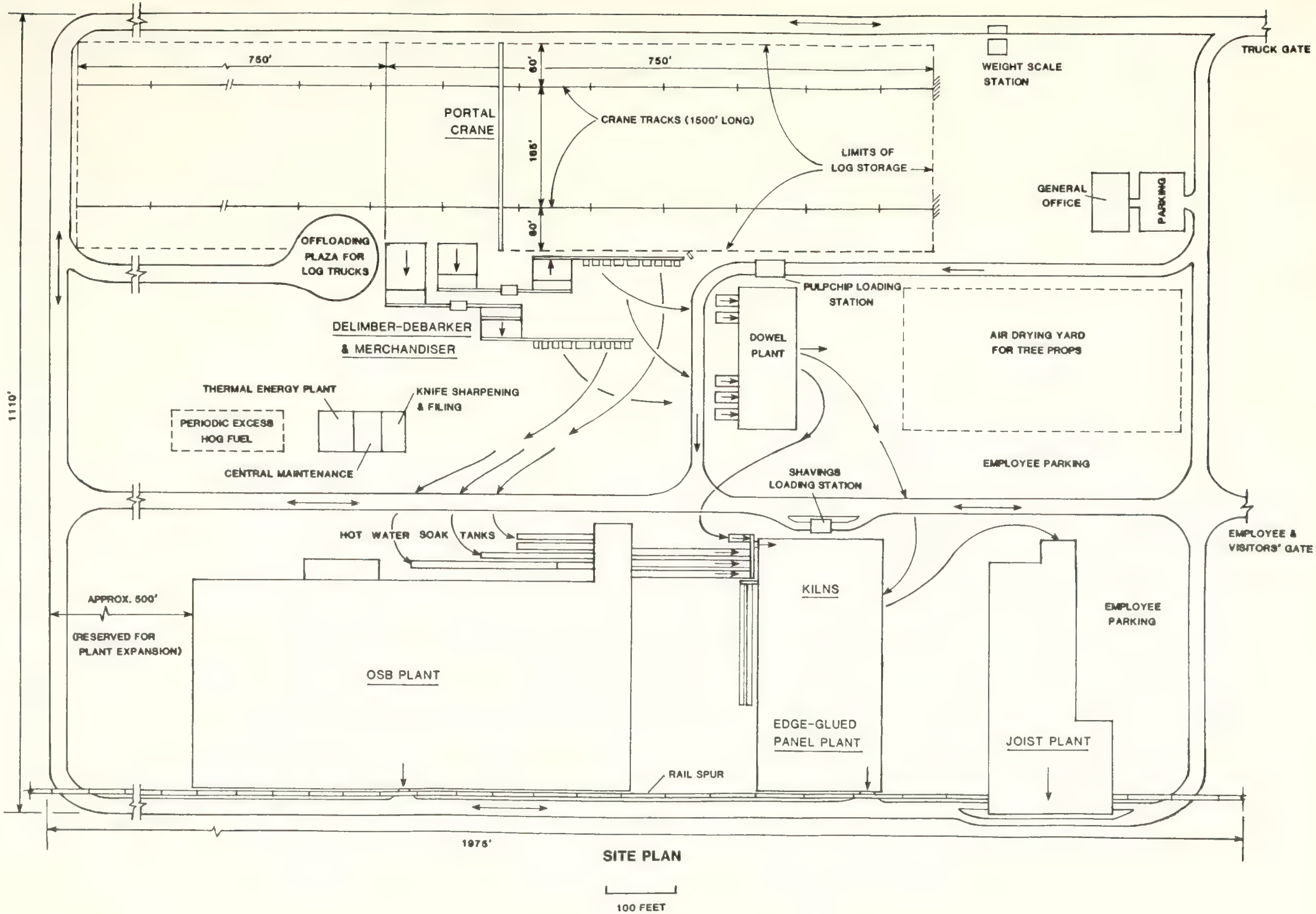

Figure 5-2—Site plan showing relationship of portal crane to the rest of the operation. Arrows from merchandiser indicate general directions of material flows.

Retrieval

The portal crane will service two infeed decks (fig. 5-3), both receiving more or less the same mix of all incoming wood—including lodgepole pine (both live and dead) and non-lodgepole pine. As noted previously, the total number of stems entering the plant annually will be 3,056,972 or 6.07 stems per minute for 350 24-hour days annually. If it is assumed that delimbing, debarking, and stem bucking activities are functional ("up" in the vernacular) 80 percent of the time, deck and machine rates must be set to accommodate a total of 7.6 stems per minute, that is, 3.8 stems per deck per minute.

Of this 7.6 stems per minute, 19.6 percent will be purchased wood with no limbs. Such logs will have a minimum top diameter of about 4½ inches and will average about 37 feet long with butt diameters averaging about 10 inches. Most of these stems will be 16 to 40 feet long, but the full length range will be 8 to 50 feet.

Of the total of 7.6 stems per minute, 80.4 percent will be whole trees with most limbs attached—mostly lodgepole pine (perhaps 5 percent non-lodgepole). About 25 percent of these lodgepole pines will have been harvested from beetle-killed stands. Top diameters will be about 1-½ or 2 inches, and length will average 34 feet, with most stems 16 to 40 feet long but with full range of 8 to 50 feet.

In an average 24 hours of operations, a total of about 10 logs with butt diameters exceeding 16 inches will be loaded on the two decks (logs too large to be processed); the rest of the logs will be smaller.

Each deck will be equipped with an extendable-reach, manned, hydraulic grapple. A minor function of these grapples will be to deposit logs with butt diameters in excess of 16 inches on portal-crane-accessible bunks for later manual bucking to yield stem sections smaller than 16 inches and larger butt sections for resale. The principal task of each hydraulic grapple will be deposition of 3.8 stems per minute (average) into a conveyor feeding a delimber-debarker.

5-3 DELIMBING AND DEBARKING

Delimbing

As reported by Kwasnitschka (1978), equipment has been in satisfactory service for a decade that will delimb whole trees of the dimensions just described at a maximum feed rate of 131 ft/min. In these operations (in Germany), the delimber is closely coupled to a mechanical ring debarker. Trees are grapple-loaded and fed butt-end first. In the proposed operation, one such delimber-debarker combination could be fed by each of the infeed decks just described. Alternatively, strap-type delimbers in common use on mobile harvesters could precede the debarkers.

Because of the small top diameters of stems in the proposed operation, it will not be practical to have speedup conveyors preceding the delimbers (as the stems would overrun each other). With infeed conveyor, delimber (and closely coupled debarker) feeding at a constant rate, it will be necessary to space the stems as they are introduced to the conveyor leading to the delimber. With stems averaging about 35 feet long, and with average gap between stems of 5 feet, conveyor speed—and hence delimber and debarker feed speed—must be about 152 ft/min.

As noted previously, about one-fifth of the stems will have been previously delimbed (the purchased wood) and will simply pass through the delimber enroute to the debarker.

Not shown in figure 5-3 is the drum chipper (fig. 5-4) specifically designed to reduce residual branches and bark to fuel particles. This chipper has a 9-foot-wide infeed conveyor delivering the branches and bark through infeed crusher rolls to a 48-inch-diameter by 64-inch-long drum chipper.

Debarking

A mechanical ring debarker will be closely coupled to each delimber and will feed at the same lineal rate. Most ring debarkers cannot remove bark from stems smaller than 2½ inches. So some bark will likely be left on many of the stem tops. Most of this small-diameter wood is to be dowelled, thus the residual bark will be removed in the dowelling process. Residue from the dowelers is unsuitable for pulp or flakeboard and will be used as fuel.

The feedworks of the ring debarker must be able to accommodate the full range of stem diameters from 1½ inches to 16 inches. Because the feed speed will be slow (only 152 ft/min), such accommodation should be practical.

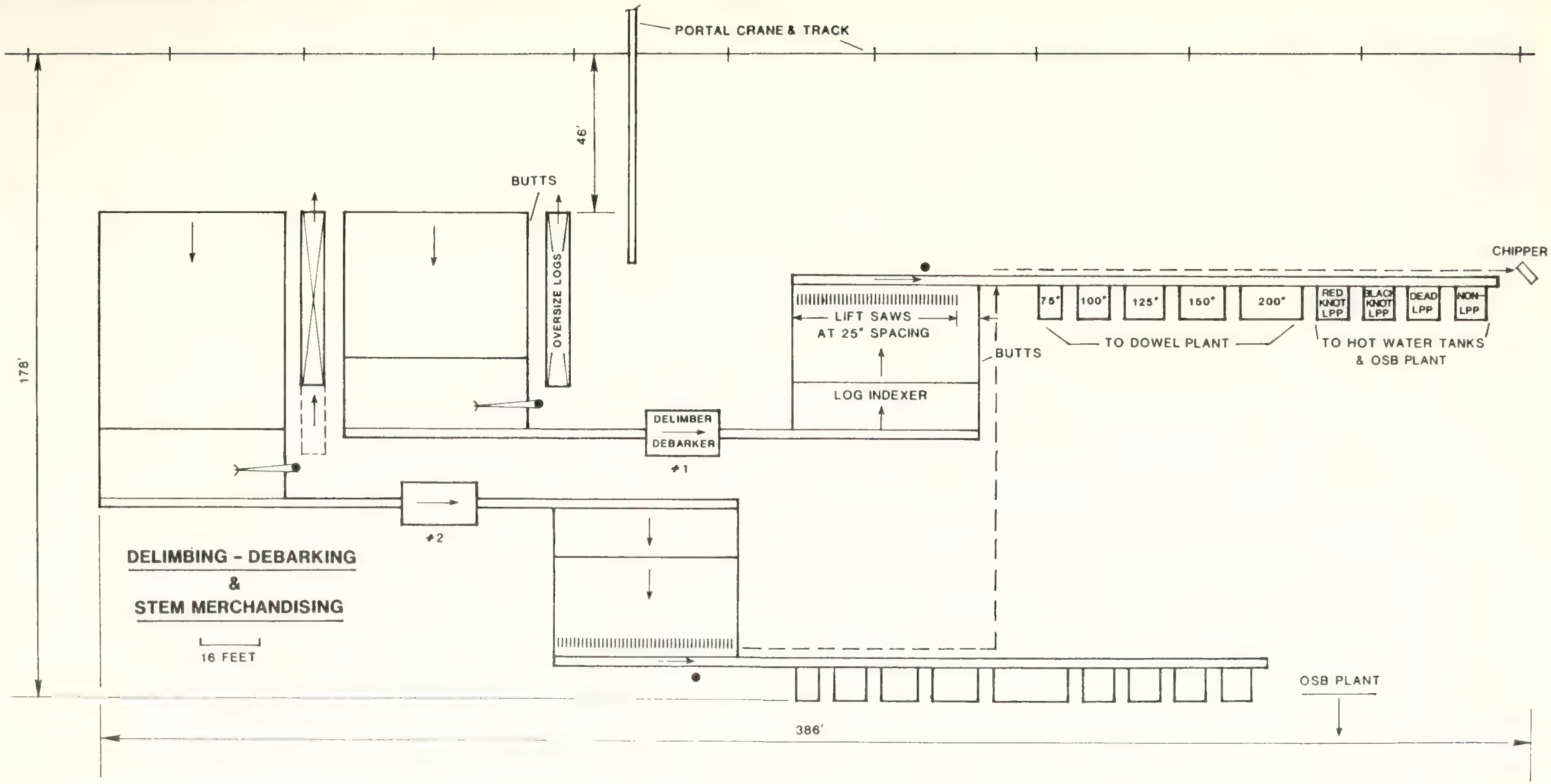

Figure 5-3—Layout of twin infeed decks, delimber-debarkers, and stem merchandisers.

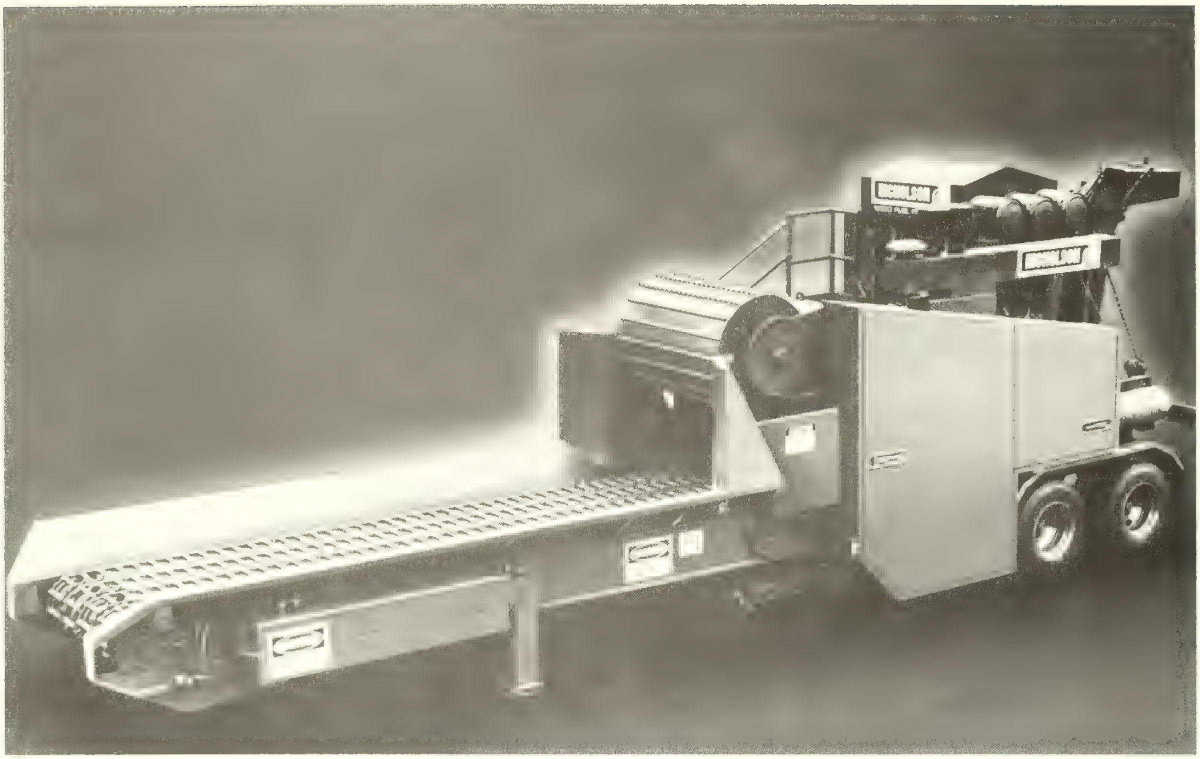

Figure 5-4—Comminution machine carrying a 48-inch-diameter, 64-inch-long drum chipper designed to chip and size branches and bark for hog fuel. (Photo from Nicholson Manufacturing Company.)

5-4 STEM MERCHANDISING

The process of crosscutting a tree stem into sections to maximize stem value is termed merchandising, and the system of machines used for this purpose is called a stem merchandiser. Beginning from the butt of the stem, the sections to be cut from the stem are as follows:

Section description	Diameters: Minimum top	Diameters: Maximum butt	Length
	Inches		
Bolts for disk flaker (OSB) can include shear-shattered butt cuts	4.0	16.0	100
Bolts for edge-glued panels			
4-inch cylinders	4.2	5.5	100
4.5-inch cylinders	4.7	6.0	100
5.25-inch cylinders	5.5	7.0	100
2.625-inch joist flanges	2.8	4.0	200
Tree props (usually 2-inch)	2.1	3.2	75,100, 125, 150
Tops and defects chipped for pulp	random		

The first and last categories in the foregoing tabulation can include all species. The other three categories are restricted to lodgepole pine only. Based on the assumptions made in section 3-2, cutting priorities will be about as follows:

Description of section	Priority
Tree props (usually 2 inches in diameter)	1
Joist flanges	2
Bolts for edge-glued panels	3
Bolts for disk flaker	4
Sections to be chipped for pulp	5

The two stem merchandisers (fig. 5-3) are identical. All products are in lengths that are multiples of 25 inches, so retractable saws are located on 25-inch centers across the width of the transversely moving merchandiser deck. As each stem, previously singulated (positioned individually) on a stem indexer, moves into position to be crosscut, the operator will punch in the sequence of products desired, the appropriate saws will move into the cut, and all severed portions of the stem will fall into a lengthwise conveyor for automatic discharge into the appropriate bins. Operator decisions based on visual grade are required because nonlodgepole pine stems must be reduced to 100-inch lengths for conversion to OSB, while lodgepole pine (both live and dead) can yield tree props, flange dowels, and bolts for edge-glued panels as well as bolts for conversion to OSB. Lodgepole bolts 100 inches long must also be separated into those with sound red knots for edge-glued panels, those with black knots for OSB, and those cut from dead trees for OSB. Additionally, some small-diameter wood is unsuitable for tree props or flange dowels, and must therefore be diverted to bolts for OSB.

As noted previously, with stem merchandiser "up" time of 80 percent, 3.8 stems per minute will be segmented on

each merchandiser. Each operator therefore has about 16 seconds to segment each stem—a time deemed sufficient for the task.

Connected electrical motors on the system of delimbers, debarkers, merchandisers, and chippers will total about 1,200 hp.

Operators staffing the portal crane, log decks, delimber-debarkers, and stem merchandisers are as follows—with all positions occupied 24 hours per day, 350 days per year:

Position	Operators per shift (exclusive of weight scaling and maintenance)
Lead operator	1
Portal crane operator	1
Operators of hydraulic grapples at infeed decks	2
Operators of stem merchandisers	2
Forklift operators transporting stem sections to storage and to appropriate plant infeed decks	2
Total	8

5-5 DOWELING PLANT

Most dowel machines in commercial use operate on the same principle. The stem section to be machined is advanced axially (without rotation) through a rotating knife ring carrying three or four knife-clamp assemblies. These knife assemblies are movable radially to adjust for desired dowel diameter to match an exactly sized collet through which the finished dowel passes. Each of the knife-clamp assemblies carries a roughing knife set to machine a sharp taper, followed by a contiguous finish knife set to machine a shallower taper and establish the desired cylindrical shape (fig. 5-5). The rotating ring that carries the knives is typically powered by a 40 kW motor, and will accommodate dowel diameters from 2 to 7¾ inches. Dowelers that can turn 1.5-inch tree props are also available.

Typically, a dowel machine has four pairs of powered, vertically self-centering infeed rolls and three pairs of similar outfeed rolls. Adjustment of the infeed rolls to accommodate stems of varying diameters is accomplished by a control wheel convenient to the machine feeder. Feed speeds available may be as high as 150 ft/min, but few are operated above 50 ft/min if quality of finish on the dowels is important. To prevent flailing of dowels on exit, some operators employ a 12-foot exit tube with a bell-shaped exit end discharging to offbearer or grading chain.

Experienced operators indicate that dry wood machines more readily (and more smoothly) than green wood. Stems machine better in summer than in winter; frozen wood is more difficult to machine than unfrozen. When wood temperature falls below 0 °F, machining is usually impractical.

To maintain feed continuity, stem sections should be accurately classified by diameter (and those with excessive taper diverted) before admitting them to the dowel machines. If stem sections are fed small end first, tree pith will be more accurately centered in the resulting dowel than if fed butt first; but machining problems are lessened (end snipe reduced) if the stem sections are fed butt first.

To maintain surface quality on the dowels, knives should probably be changed after about 4,000 lineal feet have been run. Time required to change knives and set up a machine is seldom less than 30 minutes.

Figure 5-5—This section of a partially machined dowel illustrates the function of roughing knives that produce the tapered cut and finish knives that produce the cylindrical shape. In the plant contemplated, stem sections will be bark free before passing through the dowel machine.

Dowel Plant Output and Machine Layout

As noted in chapter 3, a single doweling machine is capable of running about 2,200 small dowels averaging about 9 feet in length per 8-hour shift (mostly 2 inches in diameter, but some $1^1/2$ inches in diameter). This shortwood machine will be scheduled to run three shifts per day, 350 days per year, on tree props and on small dowels for the edge-glued panel plant. Input of stemwood to this machine will total about 12,798 tons annually, and output will total about 5,146 tons of tree props, 2,955 tons of dowels for the edge-glued panel plant, and 4,697 tons of bark-free residue—all on an ovendry-weight basis (fig. 3-8). This annual tonnage is equivalent to about 2 million 2-inch-diameter props (fig. 3-1) averaging 9 feet long, plus about 280,350 dowels 4 inches in diameter and 100 inches long for conversion to edge-glued panels. The plant layout must accommodate props 6, 8, 10, and 12 feet long. These props will be pointed, banded into packages of convenient size (fig. 5-6), and sold green or air dried, but not kiln dried.

An additional three machines will turn dowels $2^5/8$ inches in diameter for use as flanges in fabricated joists (fig. 3-2). Bark-free stem sections selected for this use will measure 16 feet 8 inches long. Output of each of the three machines should average about 1,000 such stem sections per 8-hour shift—calling for an average feed rate of 35 ft/min sustained over the full 480 minutes of the shift. If machines are operated three shifts per day for 350 days each year, scheduled annual stemwood input will total about 39,632 tons, ovendry-weight basis, with 60 percent ending as dowels and 40 percent as residues. On emergence from the doweling machines, these dowels—all candidates for flanges—will be stacked without sticks in 42- by 42-inch stackable kiln pallets and kiln dried before delivery to the joist plant for stiffness evaluation and further processing. Kilns for these candidate flanges must therefore have an output of 9,000 dowels per operating day, which amounts to an output of about 63,000 dowels per week—assuming 7 days of operation most weeks.

One additional doweling machine—a spare—will discharge onto the flange grading line (fig. 5-7). Thus there will be sufficient machine capacity to permit one doweler to be down at all times for knife change and setup.

All residues from the dowel plant will be conveyed to fuel storage facilities.

Connected power (electrical motors) in the dowel plant is estimated to total 400 hp.

Staffing

The tree-prop machine requires one feeder and one offbearer; the offbearer grades each prop, machines the two ends, and stacks it for banding (fig. 5-6).

Each of the three operating flange machines requires one feeder; all flange machines discharge onto a common grading chain from which one person pulls the dowels into stackable kiln pallets for later forklift transfer into dry kilns (fig. 5-6).

The dowel plant is therefore operated on each shift by four feeders, two offbearers, and one lead operator/setup person. Knifes are sharpened in a filing room central to the entire operation.

Additionally, a forklift operator will require time to service the infeed log decks and transfer loads of packaged tree props to the air drying yard and flange dowels

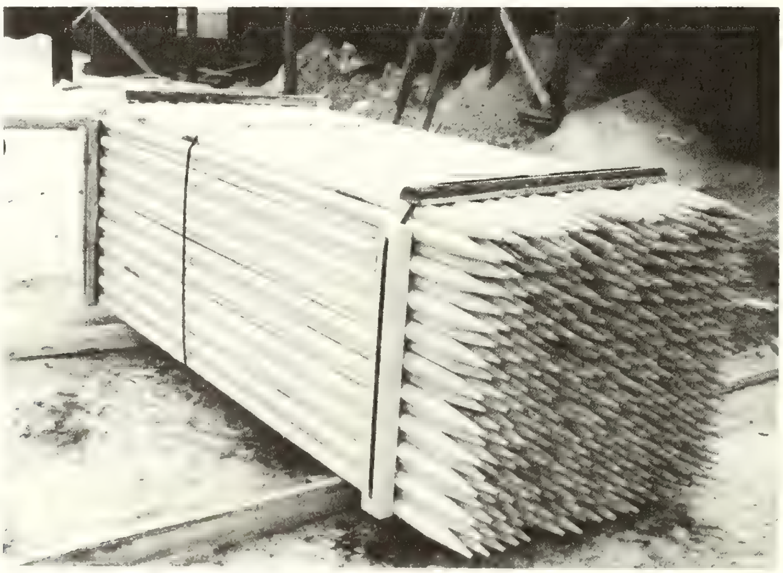

Figure 5-6—Tree props strapped in a package for shipment. To improve package stability, strapping is threaded through holes bored in the ends of each restraining strip.

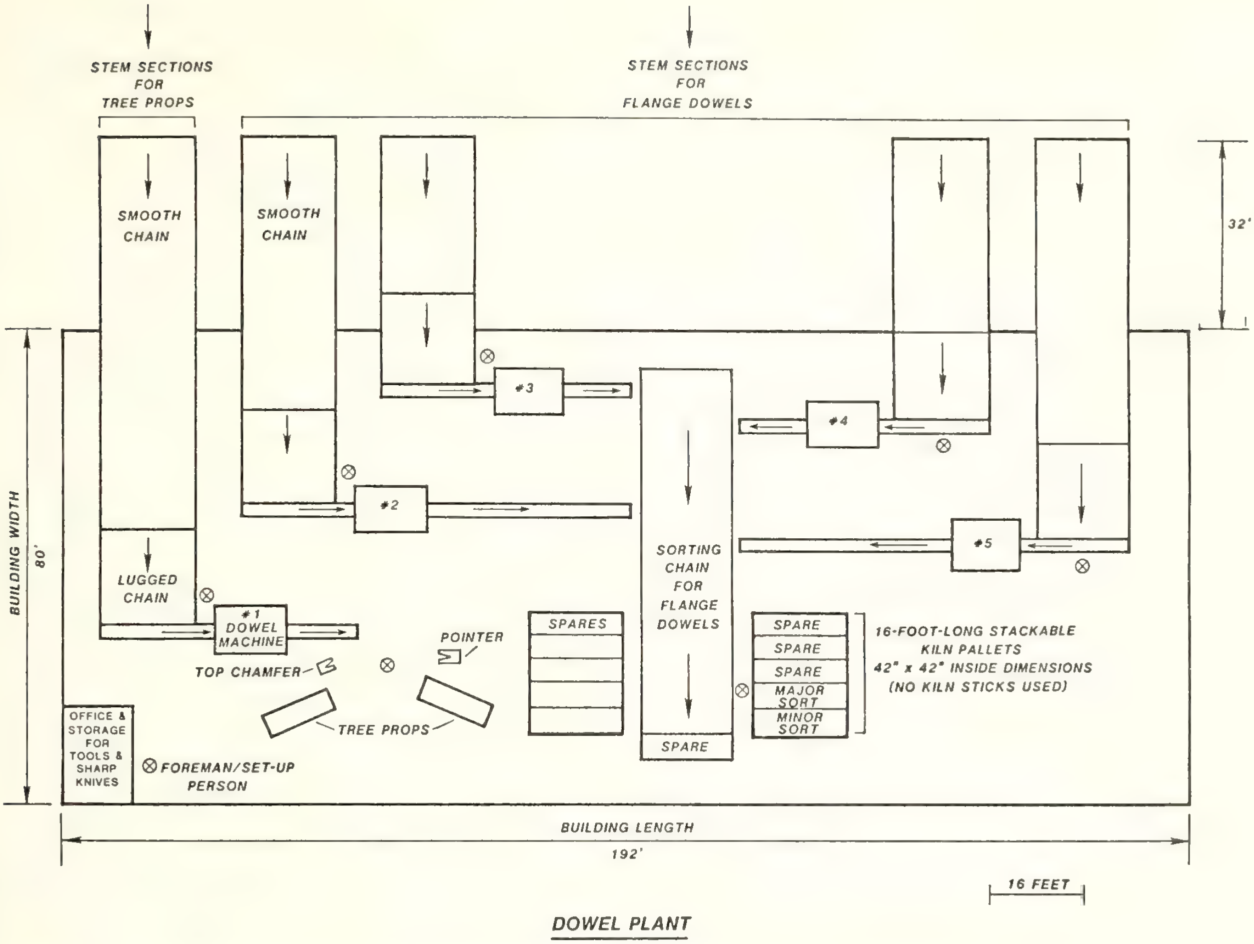

Figure 5-7—Layout of dowel plant housing five doweling machines. Typically, four of the machines will be in operation and one will be down for knife change and setup. When dowel machine #1 is down, tree props can be run on any of the other machines.

to the dry kilns. As noted previously, about 2,200 stem sections suitable for tree props or small dowels for edge-glued panels, and about 3,000 stem sections suitable for flange dowels will enter the dowel plant each shift. Exiting the dowel plant each shift will be about four banded packages of tree props, two forklift units of small dowels for edge-glued panels, and 10 stackable kiln pallets of flange dowels.

5-6 DOWEL KILN AND JOIST PLANT

Dowel Kiln

Gaby (1967) found that 55-inch-long bark-free southern pine roundwood 4 and 5 inches in diameter could be solid-piled without sticks, and kilned at 190 °F (dry-bulb temperature) to 25 percent moisture content in about 2 days. His data indicate that length of piece does not strongly affect time to dry roundwood so piled, with air circulated the length of the roundwood (through the interstices resulting from solid piling the rounds) at 600 to 700 ft/min with periodic reversals. In his experiment, wet-bulb temperature was not controlled, but with vents open throughout the test, the equilibrium moisture content reached a constant level of 3 to 4 percent early in the run.

For manufacture into joists (fig. 3-2), the dowels must be dried to an average moisture content of about 8 percent of ovendry weight, with little variation among pieces; also, moisture gradients within each piece should be minimal. The dowels to be dried in the proposed kilns are only about half the diameter of the roundwood dried by Gaby, and therefore their drying time should be shorter. Lodgepole pine is less permeable than southern pine, however, and this factor will extend drying time. In summary, it seems likely that kiln residence time for a charge of flange dowels will be about 5 days, less a few hours to unload and load the kiln with a forklift. Kiln temperatures should not exceed 190 °F and preferably will be limited to 180 °F to prevent degradation of dowel tensile and compressive strength during drying.

As noted in the last paragraph of section 5-5, the dowel plant will produce about 10 kiln pallets of flange dowels per shift. This amounts to 30 pallets per day and 10,500 pallets per year (because the dowel plant is scheduled to operate 350 days per year). The kiln should operate continuously for 50 weeks per year (350 days), and therefore

must have a holding capacity of 150 kiln pallets—that is, $(5 \div 350) \times 10{,}500$. Because exterior pallet dimensions are about 4 by 4 by 17 feet, and the pallets should probably be stacked three high, the total usable chamber width should be 17 feet and length should be about 200 feet—that is, $(150 \times 4) \div 3$. To permit kiln discharge every $2^1/2$ days, two chambers each 100 feet long are proposed. Forklift-accessible roofed cooling sheds of about the same dimensions are also required.

In addition to the two dry kilns, a third chamber of equal size—heated to about 90 °F and with air circulating slowly—will be needed to equilibrate dowels pulled, as they enter the joist plant, for redrying (fig. 5-8).

To make the system conveniently operable, numbers of stackable kiln pallets will need to be sufficient for kilns, cooling sheds, and equilibration chamber, and for accumulation of incoming charges and a working inventory in the joist plant. These needs will total about 500 pallets.

Before kiln dimensions are finalized, some research is needed to validate the assumption that dowels 2.625 inches in diameter and 16 feet 8 inches long can be kiln dried to 8 percent moisture content in 5 days.

Joist Plant

As noted previously, each of the three machines turning flange dowels will daily produce 1,000 dowels measuring 16 feet 8 inches in length. Operating 350 days per year, annual output will therefore be 1,050,000 dowels, which when admitted to the joist plant—also running three shifts 350 days per year—must be processed at a sustained rate of $6^1/4$ pieces (105 lineal feet) per minute.

On delivery to the joist plant, the dry candidate flange dowels will be processed as follows:

- Screened for a maximum moisture content of 12 percent; rejects pulled for equilibration to 8 percent.
- Screened for minimum modulus of elasticity in bending of 1.5 million lb/in^2; rejects ejected for use as fence rails or remanufacture into tree props.
- Survivors of foregoing screening smooth-trimmed on each end to square ends and to remove snipe preparatory to finger jointing, and defect-trimmed to eliminate machining and anatomical defects judged detrimental to ultimate strength in tension and compression.
- Finger-jointed, glued, joined, and radio-frequency-cured in a more-or-less continuous process, with lengths severed at 64 feet (plus 4 inches on either end as trim allowance for damage done during tension proof testing).
- Adhesive in joints more completely cured during transport to tension proof tester.
- 64-foot lengths tension proof tested; rejects recycled through the finger jointers or remanufactured into tree props.
- Machined to shape, and dado-slotted to receive flange web.
- Assembled in pairs with web glued in place, and glue cured.
- 64-foot-long joists precision end-trimmed to length.
- A small proportion of the joists proof tested in edgewise bending.
- Joists strapped in packages, wrapped for shipment, and loaded on flatcars or trucks.

Screening Dowels for Moisture Content and Modulus of Elasticity—With only 3,000 16-foot 8-inch flange dowels to be screened per shift, it seems practical to manually load them transversely directly from kiln pallets onto a lugged chain conveying the dowels past a single-saw end trimmer and passing under three noncontact moisture sensors at quarter points of dowel length. Dowels exceeding 12 percent moisture content at any of the three sensing points will be dye-marked for rejection from the chain and redrying (fig. 5-8). The lugged chain will offload all dowels transversely into a single-point deflection device that applies a 10-pound preload at the centerpoint of a 15-foot span and then senses additional deflection under an additional 20-pound load and marks only those that exceed deflections corresponding to 1,500,000 lb/in^2 modulus of elasticity. On relaxation of the proof load, all dowels will be ejected transversely onto a short grading chain. From the grading chain, an operator will pull dowels requiring redrying, and position acceptable dowels so that a single-saw trimmer will trim snipes from the grader's end. Those failing to meet the stiffness requirement, and those requiring trimming to remove machining defects or anatomical irregularities that would significantly diminish strength of the dowels in tension or compression, will be positioned by the grader for ejection to a reject pallet or to a defect-removal station and return to the chain (fig. 5-8).

In positioning the dowels for end trimming, the offloader and grader will ensure that finger joints will be made in clear wood; that is, knot clusters on dowel ends will be removed by trimming.

Finger Jointing Dowels—As noted above, about 3,000 dowels enter the screening process per shift. Some are withdrawn because they need additional drying, but these will be reintroduced periodically, so these withdrawals do not diminish the piece count going to the finger jointers. About 15 percent (510 dowels per shift) will, however, be withdrawn from the flange plant because they have insufficient modulus of elasticity; these dowels will be sold as fence rails or remanufactured into tree props. Of the remaining 2,550 dowels, about 20 percent will be crosscut into two pieces during defect removal, and reintroduced into the line. The net result of this screening and defect-cutting operation is an increase in per-shift piece count to about 3,060 dowels, about 2,040 of which are 16 feet 8 inches in length, with the balance comprised of random shorter lengths. Allocated over an effective shift length of 400 minutes, this calls for processing nearly eight dowels (that is, shaping 16 ends) per minute through the finger jointers—and curing eight finger joints per minute.

This production is too small for a fully mechanized pair of back-to-back conveyor-fed finger-joint machines which typically cut end joints and apply glue on both ends of 30 to 60 pieces per minute. Instead, a four-operator setup is proposed wherein each operator does the complete job.

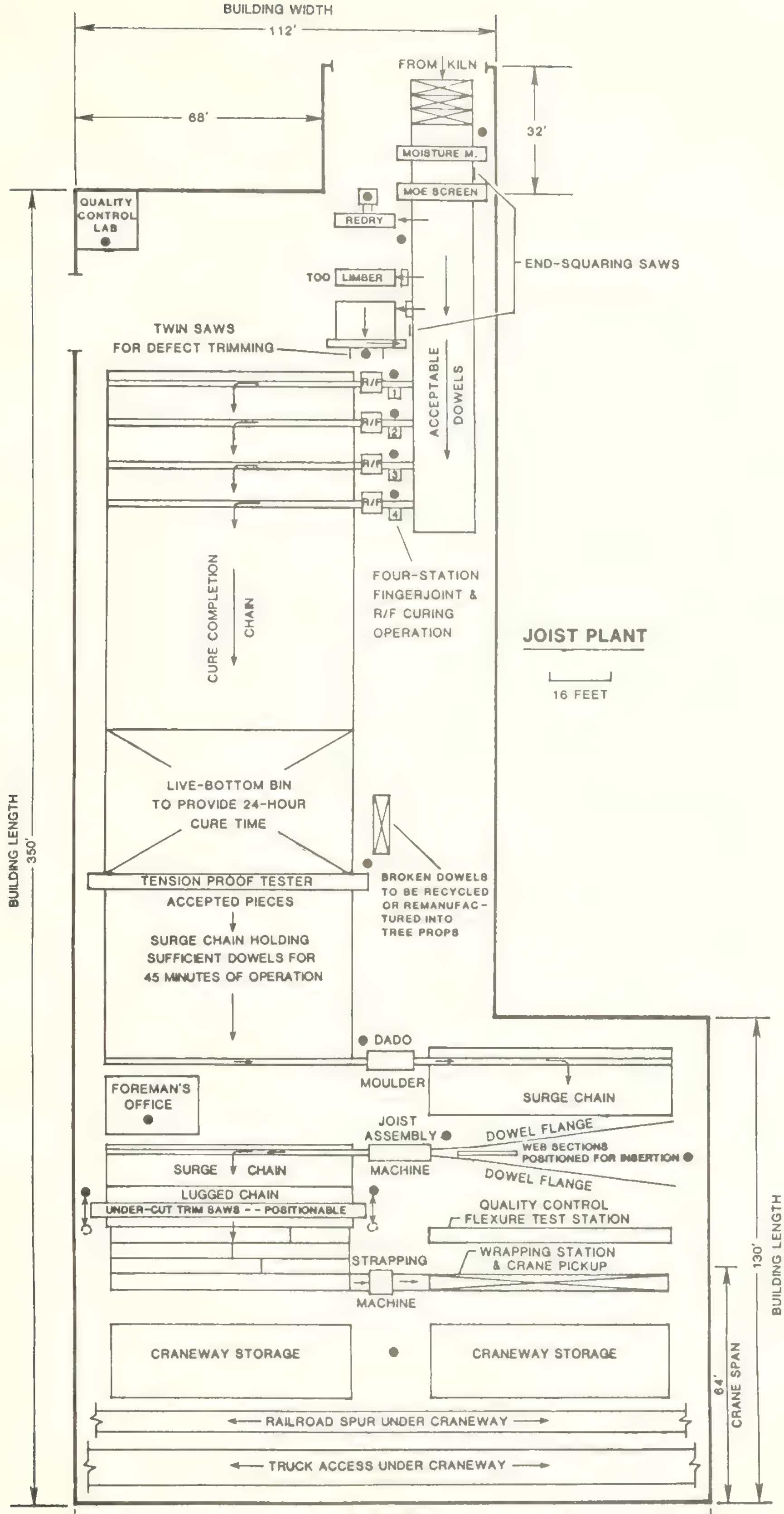

Figure 5-8—Layout of arrangement for screening kiln-dry dowels for moisture content and modulus of elasticity, and subsequent processing into joists of prescribed lengths for shipment by rail and truck.

This entails finger-jointing of both ends of dowel ends; applying to the joints glue, joining the dowels, applying pressure to the joint for curing the adhesive in a radio frequency (RF) unit, advancing the assembly (usually 64 feet plus trim allowance), crosscuttingthe assembly at desired length, and ejecting it onto the cure-completion chain (fig. 5-8). Equipment provided for this cycle must be capable of producing two assembled joints per minute at each of the four operator stations. Since each 64-foot length (usually containing four joints) will be proof tested in tension, this arrangement permits operator accountability for joint quality.

After a minimum of 30 minutes on the transversely moving cure-completion chain, the 64-foot lengths will be transversely deposited in a live-bottom surge bin providing 24 hours of storage before proof testing in tension (fig. 5-8).

Tension Proof Testing of Dowels—Following curing of finger joints in the flange dowels, each will be transversely and singly loaded from curing bin into a tension proof tester, gripped on each end, and subjected to a tension load calculated to stress the dowel flange to about 1.6 times the stress that it will incur when the joist in which it is incorporated is subjected to the joist design load. This load will be held for a minimum of 5 seconds before release and transverse discharge of the dowel to a waiting pallet for storage until introduction to the joist assembly operation.

Flange dowels failing the tension proof test will be sorted into a separate pallet for recycling through the finger-jointing stations or remanufacture into tree props. The tension proof tester will be capable of screening two flange dowels per minute. Per-shift output of acceptable 64-foot lengths will average about 638 pieces.

Dadoing and Machining Dowels—The component dowels comprising each 64-foot length will all have some sweep—averaging about 0.75 inch and not exceeding 1.5 inches. This sweep will be distributed in a variety of planes over the whole 64-foot length. Any single dowel segment can be straightened by application of a 50- to 100-pound force appropriately directed. Before a 64-foot length can be accurately dadoed, clamping or guiding action must be applied to preclude rotation and the length in the region of the dado head must be straightened in all planes and held securely while the dado head cuts.

Such clamping and machining actions can be accomplished at the production rate required (about 150 lineal ft/min) with a specialized moulder equipped with pressure feed rolls before and after the dado head assembly adequate to straighten the dowel in all planes. The dado head assembly will be comprised of two bottom cutterheads, one making a rectangular partial cut to provide a slot into which a guidance key on the moulder bedplate fits, and a second finishing head. To further resist rotation of the dowel, the bedplate following the finishing dado cutterhead will be fitted with a protruding $^3/_8$-inch-wide key to guide each dowel until it exits the moulder.

The moulder will carry two surfacing heads in addition to the two bottom-cutting dado heads. Cutting first—before the first dado head—a bottom jointer will produce a narrow flat on the bottom of the dowels. The final cutterhead on the moulder—a top head—will surface the 1.5-inch-wide flat on the top of each dowel flange (fig. 3-2).

Trials of a standard five- or six-head moulder might prove the adequacy of such standard machines, thus avoiding the extra cost of the specialized moulder just described.

Two to three pallet loads of 64-foot-long flange dowels will enter the moulder per shift, requiring one feeder. Offbearing will be automatic onto a surge chain (fig. 5-8).

Joist Assembly—The flakeboard plant will provide pallet loads of 8-foot-long web sections accurately trimmed to width and with edges prepared for glue adherance and easy insertion into the flange dadoes. Also, the webs will have die-cut circular grooves (knockouts) 1.5 inches in diameter indented at spaced intervals away from the web neutral axis (so that horizontal shear strength of the web will not be adversely affected). The infeed end of the assembly machine will be fitted with keyed guidance members, permitting pairs of dadoed flange dowels to enter on a gentle radius positioned to accurately close on the web sections as they are inserted sequentially into the assembly machine. Just before closure, glue will be applied in the dado groove; and just after closure the web-to-flange glue lines will be radio-frequency (R/F) cured so that edge pressure can be released as the joist exits the assembly machine onto a transfer deck. Alternatively—and perhaps more economically—a vinyl emulsion/isocyanate adhesive could be set in 60 seconds in a continuous press without R/F curing; the economics would depend on the price per pound of R/F curable exterior-grade adhesives (for example, acid-catalyzed phenolic with pH above 2.5, melamine, or phenol-resorcinol-formaldehyde) compared to cost of the isocyanate adhesive.

Output of the assembly machine will average about 42.5 ft/min sustained for the full shift to achieve a scheduled per-shift production of about 638 joists 64 feet in length. Because of operating delays caused by setups, glue replenishing, and infeed positioning of pallets of webs and flanges, the assembly machine will run at about 60 lineal ft/min.

The assembly machine will be fed by two operators. Glue-assembled joists will be discharged from the assembly machine onto a short transfer chain feeding a multiple-saw length trimmer.

Length Trimming of Joists—Most joists destined for rail shipment will be precision trimmed to 64-foot lengths. Joists to be trucked to market will usually be trimmed to shorter specified lengths. The trimmer will therefore be provided with undercut saws that can be positioned to produce the desired length combinations. If necessary, residual end pieces will be salvaged as precision-cut lengths of blocking.

Strapping, Storage, and Shipping—Packages of cut-to-length joists will be strapped for shipment, wrapped (weatherproofed) in pallet loads measuring about 4 feet square, and crane-lifted into temporary storage pending loading onto flatcars or flatbed trucks for transport to distribution centers. As noted previously, per-shift output of the joist plant will be about 319 64-foot-long joists (about four pallet loads), or the equivalent in shorter lengths.

Proof Testing of Joists—At intervals appropriate for the statistical precision required, sample specimens will be drawn from the piles of length-trimmed joists and proof tested in edgewise flexure to ensure integrity of published design strength values.

Connected Horsepower—Connected (electrical motors) in the joist plant power is estimated as follows:

Item	Horsepower
Conveyors incorporating moisture content and MOE determination, grading, and trimming	60
Four finger jointers and associated curing chains and conveyors	160
Four R/F curing units	20
Tension proof tester and associated conveyor	10
Dado moulder and associated conveyor	150
Joist assembly machine and associated conveyors	15
R/F curing unit for joist assembly machine	40
Double-end trim saws and conveyors	15
Strapping machine and conveyors	5
Crane	20
Fans for blowpipes	25
Hog for trim ends	20
Total	540

Staffing—Per-shift staffing of the joist plant will be as follows (not including quality controllers, filers, or maintenance crews; the kiln lead operator is tabulated under the edge-glued panel plant):

Function	Number
Lead operator of joist plant	1
Forklift operator	1
Feeder, grader, and trimmer operator for dowel-screening chain	3
Finger jointers	4
Tension proof tester	1
Moulder feeder	1
Feeders of joist assembly machine	2
Feeders and offbearers of precision joist trimmer	2
Shipper and crane operator	1
Floater	1
Total	17

5-7 PLANT FOR EDGE-GLUED PANELS

As outlined in chapter 3, contemplated annual production of edge-glued panels (figs. 3-5 and 3-8) made from 100-inch-long lodgepole pine bolts will total 11,661 tons (ovendry basis). If panels average 1.5 inches in thickness, annual production will be about 6,500,000 ft^2. Input of stemwood sections for this output is estimated at 37,002 tons annually, ovendry.

About 11.4 percent of this input tonnage will be processed through the short-wood dowel machine (fig. 5-7). Dowels so produced will generally have diameters in the range from 4 to 4.5 inches.

The output of edge-glued panels is largely determined, however, by throughput capacity of the single 100-inch shaping lathe (fig. 3-9), which is estimated at 1,680 bolts per shift turned to cylinders of prescribed size (fig. 3-4)—generally larger than 4.5 inches in diameter. Because the shaping lathe will operate three shifts per day, 7 days per week, 50 weeks per year, annual throughput will be about 1,764,000 bolts or 24,586 tons output from 32,781 tons input (ovendry-weight basis).

This shaping lathe, which will be set to produce residue in the form of flakes 3 inches long and 0.020 inch thick, will be located in the OSB plant adjacent to the disk flaker.

As noted earlier, sound red-knotted 100-inch-long lodgepole pine bolts of appropriate diameter for the edge-glued panels will be diverted into holding bins at the merchandiser. The smaller bolts so diverted will go directly to the short-wood dowel machine, and resulting dowels will be forklifted to a short infeed deck feeding the resaw in the panel plant.

Larger bolts will be forklifted into a hot-water conditioning tank dedicated to feeding the shaping lathe. The layout (see fig. 5-11, p. 66) is such that the occasional misallocated black-knotted bolt can be diverted, as it exits the hot-water tank, to the disk flaker. It is anticipated that about 40 percent of all of the 100-inch bolts of live lodgepole pine in the desired diameter range will be suitable for edge-glued panels.

The shaping lathe is capable of accepting bolts within a range of diameters and making a set for each bolt to achieve maximum prescribed cylinder diameter—in random order. As the machined green cylinders exit the shaping lathe, they will be automatically sorted into live-bottom bins according to diameter (figs. 3-4 and 5-11). These bins will discharge directly into the plant for manufacture of edge-glued panels (figs. 3-5 and 5-2).

Although residence time in these diameter-sort bins must be sufficiently short to preclude development of drying checks, each bin (really a storage deck) must have a holding capacity for a 4-hour run on the bandsaw that follows (fig. 5-9). Holding capacity of each diameter-sort bin will therefore total about 3,600 machined cylinders; thus the bins will measure about 4 feet deep and 150 feet long.

On delivery of the turned cylinders to the plant for edge-glued panels, the following sequence of operations will be performed (fig. 5-9):

- Center splitting the cylinders on a band resaw (in some cases removing a pith-centered stud).
- Kiln drying the half cylinders (and some studs yielded from center cuts).
- Face jointing and oversize blanking the kiln-dry half cylinders; planing the studs on all four sides and double-end trimming them.
- Moulding the blanked half cylinders to trapezoidal shape (fig. 5-10).
- Edge-gluing the trapezoids into panels, sanding the panels, ripping them and double-end trimming them to market size, and packaging them for shipment.

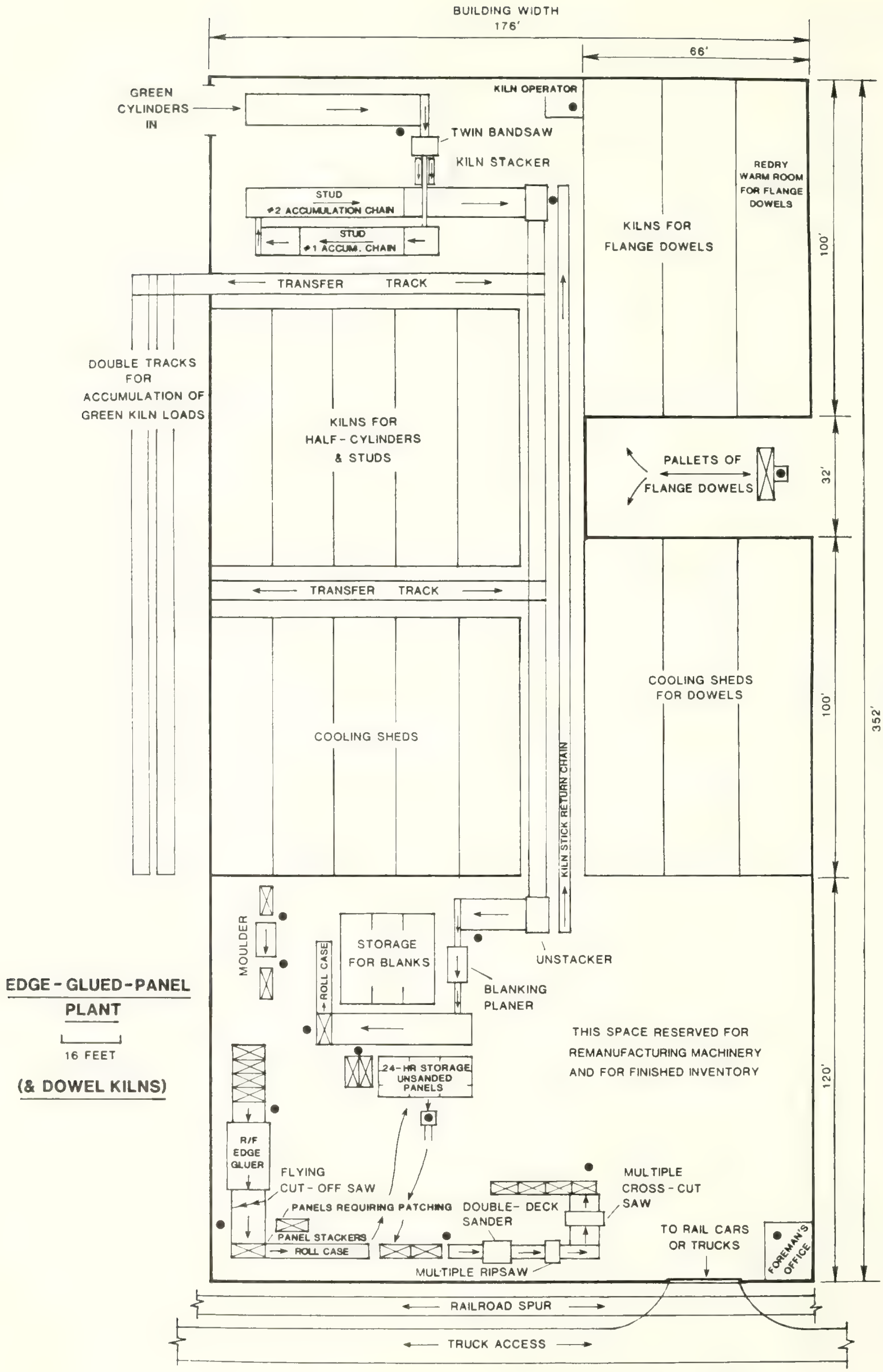

Figure 5-9—Layout of plant for manufacture of edge-glued panels, and arrangement of kilns and cooling sheds for flange dowels.

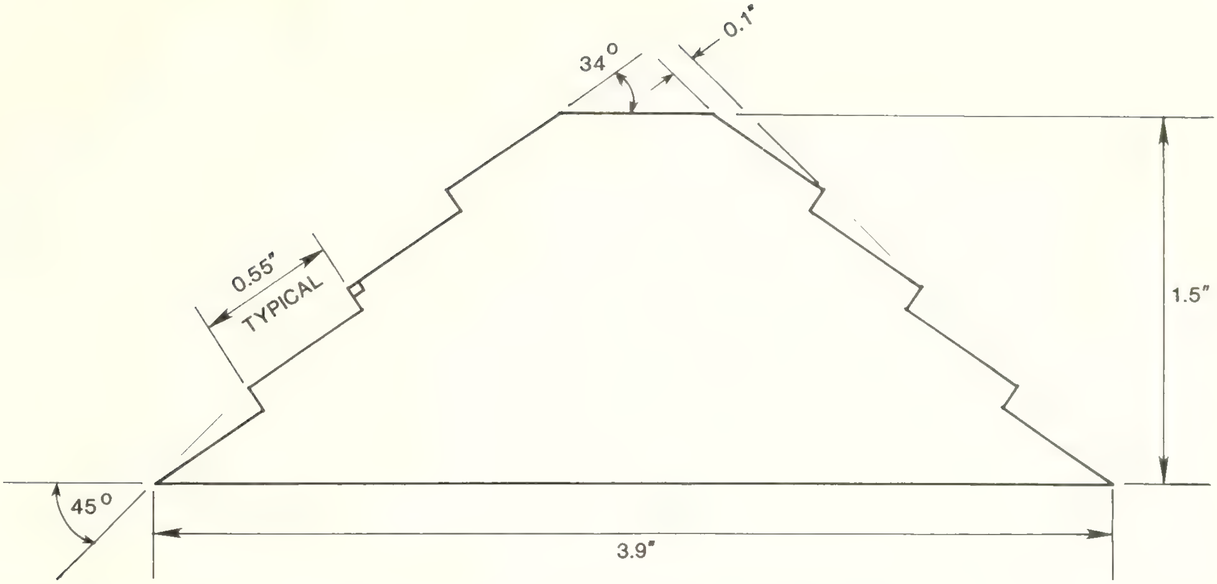

Figure 5-10—One design of edge profile for components of 1.5-inch-thick panels; these components will be cut from half cylinders with diameters (after kiln drying and crook removal) of 4 inches. Profiles for components of panels of other thicknesses will be similar, but not identical. Alternative toothed patterns are possible.

Bandsawing Cylinders

Single-shift, 5-day-per-week operation of the bandsaw is planned. Because annual throughput will be about 1,960,350 100-inch bolts (1,680,000 from the shaping lathe and 280,350 from the short-wood dowel machine), the bandsaw splitter must average 17 bolts per minute (142 lineal ft/min) sustained for each full 480-minute shift. To achieve this average feed speed, the bandsaw must run at about 175 ft/min. About two-thirds of the cylinders will simply require center ripping (fig. 3-4). The remaining third will yield a pith-center stud, and therefore a twin saw will be required. As noted previously, the cylinders will have been sorted by diameter before introduction to the bandsaw, so feed speed can be adjusted for each particular sawing job. The half cylinders will exit onto a transfer chain feeding an automatic stacker. One feeder will be required, and one offbearer who will operate the automatic stacker equipped for insertion of kiln sticks into packages measuring 6 feet wide by 12 feet high. Kiln packages will be handled on kiln trucks and transfer cars.

Pith-centered studs produced will be ejected onto a second accumulation chain with capacity to hold about 1,000 pieces. During interruptions of bandsaw operations (for saw change or setup), these studs will be conveyed onto the end of the transfer chain leading to the automatic stacker (a 6-by 12-foot kiln stack of studs will hold about 935 pieces).

Kiln Drying Half Cylinders and Studs

Kiln holding capacity is based on the time estimated to dry each charge to about 8 percent moisture content. Research data specific to half cylinders are not available, but data on drying 2 by 4 lodgepole pine lumber (Kimball and Lowery 1967; McMillen 1976; Salamon and McIntyre 1971; Troxell 1976) suggest that a 5-day schedule at temperatures not exceeding 190 °F should be sufficient. Temperatures above the boiling point of water should probably be avoided because such high temperatures tend to alter wood color from white to yellowish.

Annual production of half cylinders will total about 3,920,700 pieces, or about 5,446 kiln packages measuring 6 feet wide, 12 feet high, and 100 inches long. Annual production of 2 by 4 studs will total about 750,000 pieces, or about 853 kiln packages with dimensions just described. The foregoing figures are based on using kiln sticks 0.75 inch thick.

The kilns should operate 7 days per week, 50 weeks per year—that is 350 days annually. With an average kiln dwell time of 5 days (70 charges annually), and with double-track kilns, total kiln chamber length needed will be about 382 feet. An arrangement of five kilns each 77 feet long should suffice. The kilns will be equipped with reheat pipes at midwidth between the two 6-foot-wide packages in each double-track kiln.

Roofed cooling sheds of about the same capacity as the kilns are also required.

Face Jointing and Thickness Blanking

An unstacking machine operated by a feeder, with provision for return of kiln sticks to the kiln stacker, will discharge the dry half cylinders (or studs) across a short transfer chain to a six-head planer and matcher. The primary purpose of this machine, which must feed at about 400 ft/min (48 pieces per minute), is to remove most twist from the ripped faces of the half cylinders, to thickness the

blanks oversize thus exposing their knot structure, to establish a more-or-less straight edge for placement against the guide in subsequent moulding operations, and to machine (oversize) the two beveled faces required (fig. 3-4).

The face-jointing (blanking) machine will discharge onto a short grading chain with space to pull black-knotted wood or excessively warped wood not suitable for edge-glued panels; these rejects will be remanufactured into lumber less demanding in knot structure and straightness. The great preponderance of the face-jointed trapezoidal blanks will flow over the end of the chain into an automatic restacker for forklift transport to a moulder. Rejects should be few because of careful grading of the bolts admitted to the center-splitting resaw. One person will identify and pull the rejects, and another will operate the restacker for acceptable wood.

When planing studs, only four heads in the planer and matcher will be employed to surface the studs to 1.5 by 3.5 inches. The transverse grading chain will be equipped to permit double-end trimming of studs following planing, but before restacking. These trim saws will be lowered out of the way when blanking half cylinders.

Moulding

The edges of the trapezoids machined during moulding (fig. 5-10) must be of glue-joint quality; snipes and machine gouges will be unacceptable. While it would be possible to produce the trapezoids on a single planer and matcher operated at 336 ft/min for one shift per day, the reject rate from such an operation might be unacceptably high. An alternative is three-shift operation (243 days per year) of one manually fed moulder yielding 20 knife cuts per inch at a feed speed of 115 ft/min. A moulder appropriate for the job would have jointable spindles carrying eight-knife cutterheads operating at 3,450 r/min. To machine the trapezoids with minimum degrade, such a five-head moulder would have a bottom surfacing head followed by a top thicknessing head and then a pair of tiltable (45 degrees) sideheads to make the finishing side cuts on the trapezoids (fig. 5-10).

Such a moulder operation requires one feeder and one offbearer per shift, with incoming and outgoing loads handled by forklift (about three loads outgoing per hour).

Edge Gluing

As noted earlier, annual production of edge-glued panels should total about 6,500,000 ft^2 (average panel thickness of 1.5 inches). When produced on a single-shift basis, 243 days per year, this is equivalent to 26,749 ft^2 per shift or 105 4- by 8-foot panels per hour. To achieve this output per shift, the 100-inch-long trapezoids must have average edgewise feed speed through the panel edge-gluing press of 7 ft/min sustained for all 480 minutes of the shift. Operating feed rate of the panel press should therefore be about 9 ft/min.

Because of the edge bevels and multiplicity of rather narrow pieces (approximately four glue lines per foot of panel width), glue line area to be cured is large. To minimize length of the continuous press (fig. 5-9), glue lines will be cured with R/F energy. On emergence from the press, the continuous panel will be ripped "on the fly" to a standard width of 48 inches and automatically stacked—at a rate of three to four forklift packages per hour. A second stacker will be provided to accept panels that need patching or remanufacturing to eliminate defects.

An alternative possibility is a batch press for which preloads are assembled in about 48-inch widths and edge ripped to yield a square edge for application of edge pressure. This alternative arrangement would provide more positive edge pressure than the continuous press, but would entail greater wastage in edge trim. Additionally, a batch press might be designed to accommodate stock long enough to make 9-foot garage door rails—a product of high value. Dowels for such longer stock would come from the short-wood dowel machine.

In either case, the acceptable 48-inch-wide, 100-inch-long panels will proceed, after moisture equilibration in stacks, through a wide-belt double sander, and then through smooth-cutting ripsaws and crosscut saws to machine the panels to market size for shipment.

Although machine location is not detailed in the layout (fig. 5-9), space is provided for later addition of remanufacturing equipment such as a moulder, a router, a double-end tenoner, a shaper, and a lathe—all of which may be required to fully exploit the market potential of the edge-glued panel product.

Connected Horsepower

Total connected horsepower for the edge-glued panel plant and for all the kilns should be about as follows:

Item	Horsepower
Kilns including transfer cars, but not stackers or unstackers	1,300
Twin bandsaw with associated infeed and outfeed conveyors	190
Stacker	30
Unstacker	30
Blanking planer and matcher with associated conveyors	220
Moulder	80
R/F edge gluer panel press and associated conveyors and stacker	100
Double-deck sander and associated conveyors	100
Multiple ripsaw, multiple crosscut saw, and associated stacker	100
Fans for blowpipes	75
Total	2,225

Staffing

Staffing for the edge-glued panel plant should be about as follows (all operating a single shift, 243 days per year; except for the moulder feeder and offbearer who are scheduled for three shifts, 243 days per year):

Function	Number of persons
Plant lead operator	1
Kiln lead operator	1
Forklift operator	1
Bandsaw feeder	1
Kiln stacker	1
Kiln unstacker feeding blanking machine	1
Offbearers behind blanker	2
Moulder feeder (three shifts, 243 days)	3 (that is 1 x 3)
Moulder offbearer (three shifts, 243 days)	3 (that is 1 x 3)
Feeder of R/F panel edge gluer	1
Stacker operator behind panel gluer	1
Feeder of double-decker panel sander and trim line	1
Offbearer from trim line	1
Total persons on payroll (exclusive of quality controllers, drivers of log forklifts, and of centralized filing and maintenance personnel)	18

5-8 FLAKEBOARD PLANT

As noted earlier (fig. 3-8), the flakeboard plant will annually produce about 83,535 tons, ovendry basis, of OSB sheathing; this is equivalent to about 137.083 million ft^2 of panel, $^3/_8$-inch thickness basis. It will also produce 9,365 tons of flakeboard for joist webs, equivalent to 14.271 million ft^2 ($^3/_8$-inch basis). Web flakeboard will be significantly more dense than the OSB sheathing.

Soak Tanks and Flake Production

Soak Tanks—Warm-water heating of wood before it is flaked reduces cutting power required, improves flake quality, and softens knots. Such heating is advantageous the year around, and is particularly needed during the winter months when the wood may be frozen. A wood temperature of about 110 °F is appropriate for lodgepole pine and associated species. Heating time varies with ambient wood temperature, class of wood, and manner of flaking, approximately as follows (water temperature of 150 °F):

Class of wood	Summer	Winter
	- - - Hours	*- - -*
Live lodgepole pine	5	9
Douglas-fir and larch (larger in diameter than the lodgepole)	8	15

Because the live lodgepole pine to be flaked by the shaping lathe (figs. 3-4, 3-9, and 5-11) needs to be heated to a depth of a little more than an inch (just sufficient for roundup into cylindrical shape), it needs less heating time than that going to the disk flakers—perhaps 4 hours in summer and 7 hours in winter.

The dead (bark beetle-killed) lodgepole pine requires more soaking time because it may be very low in moisture content. The first portion of the tanks will therefore be filled with hot water (150 °F) and the second portion with cool water, which will hasten penetration of the absorbed hot water into the center of bolts (for the same reason that a hot preservative dip followed by a cold dip promotes preservative penetration). Research data available are insufficient to accurately predict the soak time required, but it will be significantly longer than for live wood.

The data in table 5-1 and subsequent discussion suggest that holding capacity of the hot-water tanks (fig. 5-11) should be about 2,000 bolts for live lodgepole pine going to the disk flaker, 1,500 bolts for live lodgepole going to the shaping lathe, and about 2,500 bolts for the non-lodgepole pine wood. A tank 5 feet deep and 120 feet long should be adequate for winter heating of the live lodgepole bolts going to the disk flaker. The tank could be as short as 65 feet for the live lodgepole going to the shaping lathe; because of the need to minimize dry-deck storage time of these bolts, however, the hot-water tank will be 120 feet in length—thus providing needed surge storage without risk of check development. The non-lodgepole wood will require a tank about 166 feet long. It is estimated that the beetle-killed lodgepole pine will require a hot tank about 200 feet long followed by a cold tank about 64 feet long. Before the tanks are designed, validation of these heating times and tank dimensions will be required.

To feed the tanks at the rate at which bolts are withdrawn, the yard forklift must maintain an infeed rate of about 800 bolts per hour, 24 hours per day (table 5-1).

Table 5-1—Distribution of classes of 100-inch-long wood entering the flakers

Flaker and class of wood	Ovendry annual tonnage	Ovendry tons/shift[1]	Midpoint average bolt diameter	Bolt weight	Bolts/shift	Bolts/minute[2]
	Tons	*Tons*	*Inches*	*Pounds*		
Disk flaker						
Dead lodgepole	22,000	22.00	5.00	30.49	1,443	3.01
Live lodgepole	41,281	41.28	6.00	43.90	1,881	3.92
Non-lodgepole	45,000	45.00	7.25	64.10	1,404	2.93
Shaping lathe						
Red-knotted lodgepole	32,781	32.78	5.66	39.02	1,680	3.50
Total	141,062	141.06			6,408	13.36

[1]Based on three shifts per day, 350 days per year, less one shift per week devoted to maintenance.
[2]Based on a 480-minute shift.

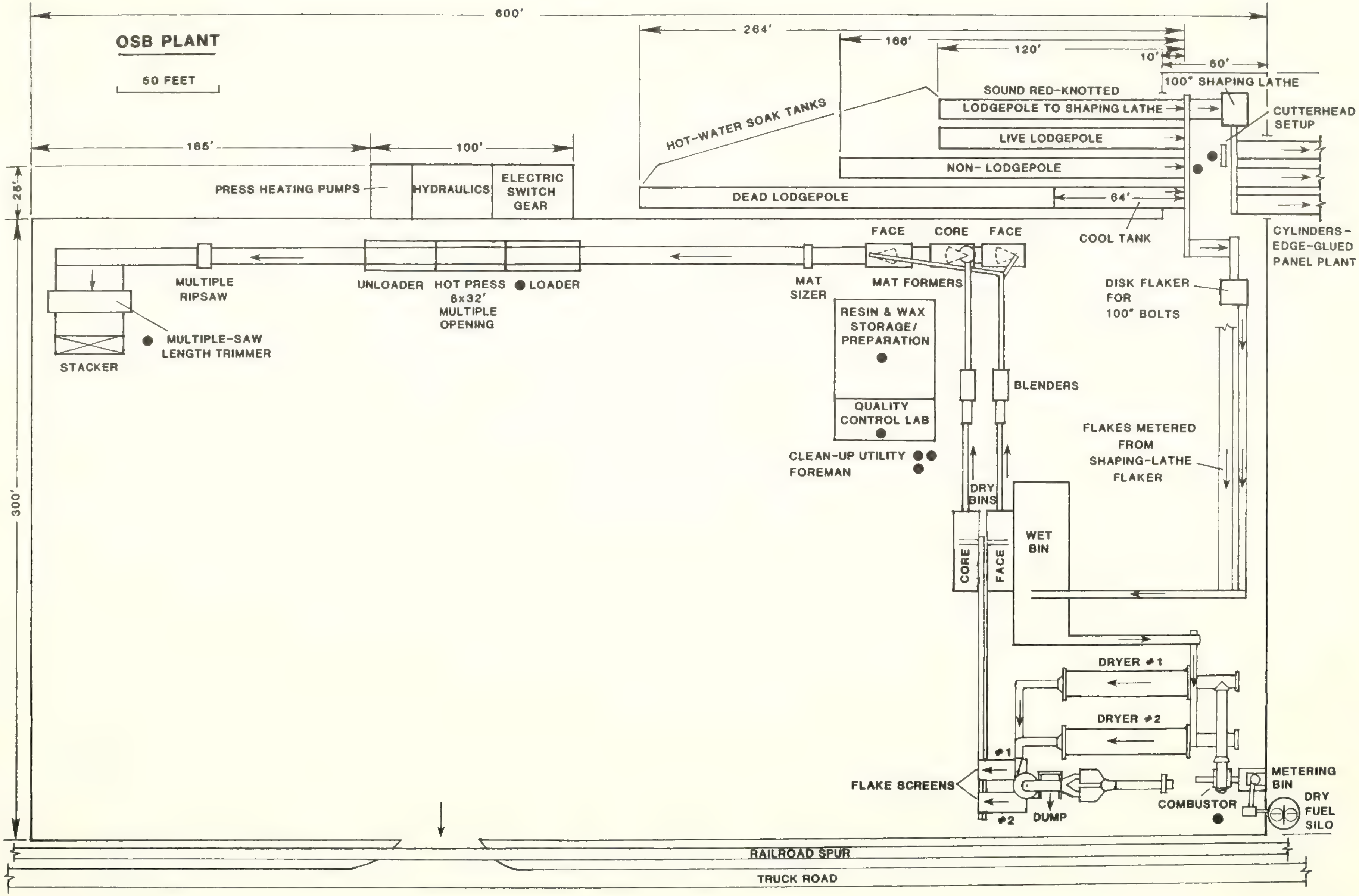

Figure 5-11—Layout of flakeboard plant, showing hot-water soak tanks (leading to the flakers) at the infeed end of the plant. The plant, principally designed to manufacture OSB panels, will also produce flakeboard with random orientation of flakes for pole-joist webs, and could produce oriented-strand lumber.

Flake Production—The infeed end of the plant (fig. 5-11) will be serviced by two flaking machines—a shaping-lathe headrig designed to turn 100-inch-long cylinders of prescribed diameter from sound, red-knotted, live lodgepole pine (figs. 3-4 and 3-9) yielding a residue of flakes 3 inches long and about 0.020 inch thick, and a magazine-type, moving-vertical-disk flaker designed to handle 100-inch-long wood. The shaping-lathe will annually produce about 8,195 tons of flakes (near 100 percent of its capacity), while the disk flaker will annually produce about 108,281 tons (about 54 percent of its capacity), for a total of 116,476 tons, ovendry basis. Additionally, the shaping lathe will yield about 24,586 tons of machined cylinders, ovendry basis. Total wood entering the soak tanks will therefore total 141,062 tons annually.

All bolts entering the plant from the merchandiser (figs. 5-2 and 5-3) will be 100 inches long, but they will have been previously sorted into four classes of wood: sound, red-knotted wood intended for the shaping lathe (and conversion to edge-glued panels), live lodgepole pine not of suitable grade or diameter for edge-glued panels but suitable for flakeboard, dead lodgepole pine, and non-lodgepole—principally subalpine fir, Douglas-fir, and larch. It is estimated that three or four bolts of each class will enter the flakeboard plant per minute, 24 hours per day for 350 days per year (table 5-1). With one shift reserved for maintenance per week, and with 400 minutes per shift of actual flaker operation, about 4.2 bolts per operating minute must be processed on the shaping lathe, and about 11.8 bolts per minute on the disk flaker.

In the layout of the shaping-lathe flaker, particular attention must be given to providing a surge bin from which shaping-lathe flakes can be evenly metered to mix with the disk-cut flakes. This surge bin is required because the shaping lathe produces concentrated flows (lasting about 6 seconds) of flakes about four times per minute. The long-log disk flaker will also produce flakes in intermittent flows (lasting about 13 seconds) timed at about three flows per minute. The wet flakes will be discharged into a live-bottom wet-flake storage bin (fig. 5-11) prior to being metered by picker rolls into a conveyor to the dryers. A flake breaker (to reduce flake width) may be interposed between wet bin and dryers.

One person should be able to feed both flaking machines and at the same time maintain a more-or-less uniform and balanced mixture (table 5-1) of classes of wood entering the disk flaker. Another person will be required full time on each shift to maintain the knives in the two machines. Knife grinding will be done in a centralized facility.

Flake Drying and Screening

As noted previously, annual tonnage of flakes produced will total 116,476 tons, ovendry basis. Because all machines in the flakeboard plant will operate 24 hours per day 350 days per year, with only one shift shut down weekly for maintenance, hourly output of the flake dryers must average about 15 tons, ovendry basis.

Flake Drying—If average moisture content of the wet flakes is 100 percent of ovendry weight, then the dryers must evaporate about 28,000 pounds of water per operating hour. With two dryers in service, each must evaporate 14,000 pounds of water per hour, requiring—at 100 percent efficiency—about 16 million Btu per hour per dryer. To avoid excessive air pollution from the dryers, dryer inlet temperatures will generally not exceed 900 °F. Engineers experienced in rotary-drum dryer design suggest that two triple-pass dryers be employed, each 12 feet in diameter and 60 feet long. Each such dryer has a heat capacity of about 40 million Btu per hour. Flakes discharged from the dryers should have a moisture content of about 2 percent of ovendry weight.

As noted above, inlet temperature to the dryers should be about 900 °F. For this reason, most flake dryers are direct-heated with hot exhaust gases from a dry-fuel suspension burner; in such burners the exhaust gases, which have temperatures in excess of 1,200 °F, are mixed with ambient air to achieve the desired (lower) inlet temperature. The suspension burners are typically fueled with dry-flake fine screenings, and with trim from the finished OSB.

In the proposed operation, however, green hog fuel is in excess supply and dry-flake screenings can be sold to regional particleboard plants. For this reason, it is proposed that the primary heat for the flake dryers come from exhaust gases from the hog-fuel-fired thermal energy plant (fig. 5-2), and only peaking heat come from the dry-fuel-fired suspension burner in the OSB plant (fig. 5-11). The thermal energy plant will therefore require special provision for higher than normal exhaust-gas temperature—that is, at least 1,000 °F. (See also discussion in section 5-11.)

One person will be required on each shift to monitor the dry-fuel suspension burner and the flake drying and screening processes.

Screening—Dry flakes, after passing a fire dump, are discharged through an airlock to two rotary-drum screens to separate the flakes into three categories: fines for fuel (or sale), surface layer strands, and core flakes (the overs).

Fines to be sold are diverted to the shavings bin (fig. 5-2); those to be used as fuel are put in silo storage, withdrawn and hammermilled, and then metered to the suspension burner providing heat for the dryers (fig. 5-11).

Dry face flakes and core flakes are conveyed to their respective live-bottom storage bins and metered out by picker rolls.

Blending of Resins and Flakes

Core and face flakes are withdrawn from the dry storage bin under continuous control of conveyor-mounted weight monitors. The continuously weighed core flakes and face flakes are separately blended with appropriate resins and slack wax. For OSB, and for random-arrangement flakeboard for webs, the conventional resin is phenol-formaldehyde (P-F), but under some circumstances (that is, when pressing 1.5-inch-thick oriented-strand lumber) it may be desirable to employ isocyanate resins in the core layer. The resin and wax preparation room is therefore equipped to mix and appropriately meter phenol-formaldehyde resins, catalysts, and isocyanate resins—as well as wax additives.

Mat Forming

Face Layers—For flakeboard to be utilized in webs, flakes in face layers are randomly oriented. For OSB or oriented-strand lumber, face layers (top and bottom) are continuously formed of strands oriented with axes parallel to the long dimension (32 feet) of the products—that is, parallel to the direction of travel of the forming belt (fig. 5-12). Bottom surface layers are deposited on this wide belt (nominally 8 feet wide) traveling underneath the forming station. The core layer is then deposited, and the top-surface layer former completes the mat forming operation. Thus there are two face-layer formers and one core-layer former (fig. 5-11). The disk-roll forming heads of the surface-layer mat formers have a separating effect, so that the small-size flakes will be deposited onto the belt and on top of the surface layer. In case the largest flakes are wanted on the outer surfaces of the mat, the disk heads need only be turned 180 degrees to achieve this effect.

Core Layer—In flakeboard for joist webs, flake orientation in the core is random. For OSB panels (fig. 3-6), however, core flakes are oriented across the panel in the 8-foot direction, that is, perpendicular to the direction of belt travel. In oriented-strand lumber, core flakes must be aligned in the same direction as the face flakes. This is accomplished by providing a mechanism to turn the core-aligning mechanism 90 degrees to suit the product to be manufactured.

Mat Sizing—The endless, three-layer mat ribbon is transported continuously on a belt conveyor. The weight of the mat is checked, extraneous metal is eliminated, and the ribbon is crosscut to raw mat length (nominally 32 feet) and trimmed to width (nominally 8 feet).

The mats are accelerated by a belt conveyor to provide a gap between mats, required for loading of the hot press within the press cycle.

For manufacture of oriented-strand lumber, which requires a thick mat, it may be that use of a newly developed tacky phenol-formaldehyde resin will permit use of a prepress to reduce mat thickness prior to press loading. Additional research is needed on this aspect of the plant layout.

Pressing

As noted in section 3-2, the flakeboard plant will be equipped with an eight-opening hot press having platens sized to produce trimmed flakeboard panels or oriented-strand lumber 8 feet wide and 32 feet long. An elevator-type mat loader will precede the press, and a panel unloader will follow the press. Thus the length of press with mat loader and panel unloader will be about 105 feet (fig. 5-11).

The platen-type caulless hot press will convert the formed mat of flakes into a bonded panel of desired thickness by densifying it to develop adequate contact between flakes, and by heating it to glue-line temperatures at which the binder cures rapidly.

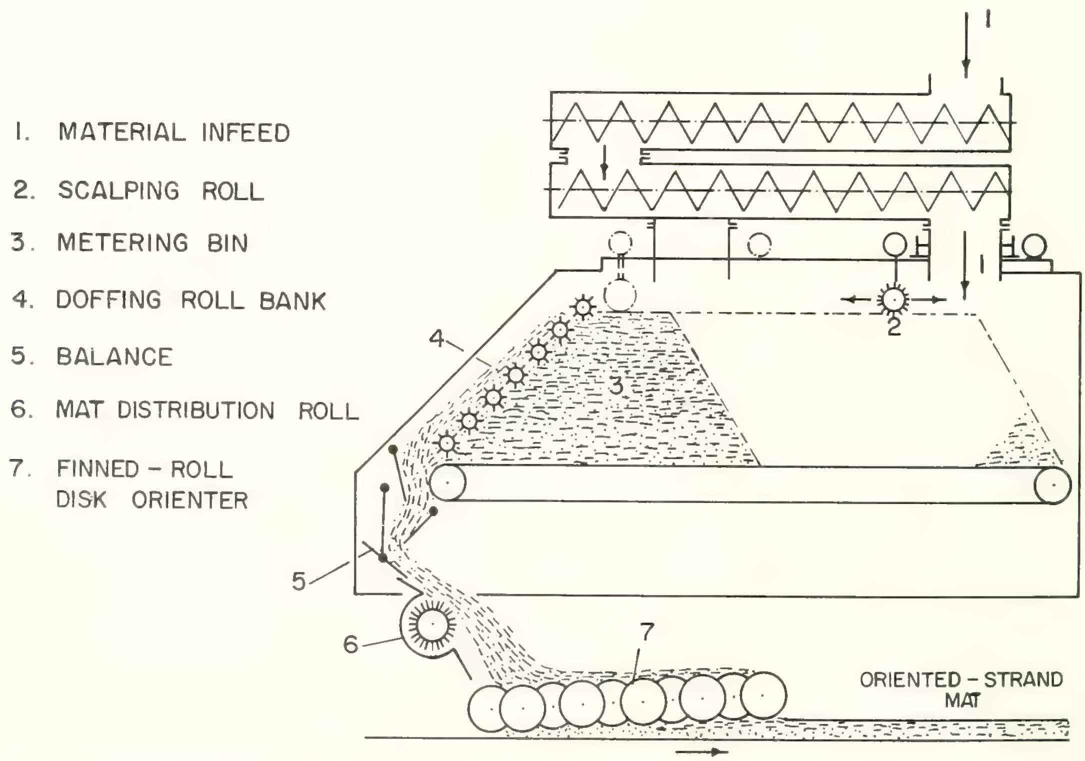

Figure 5-12—Oriented-strand board mat formation. Side elevation of forming head and finned rolls that orient the strands; because most OSB products have three layers, three heads are required to form the complete mat.

Multiple-opening hot presses capable of delivering the high pressures required for flakeboard and oriented-strand lumber are very expensive, and plant capacity is usually determined by press output. This output increases as press cycle time is decreased. For 7/16-inch-thick OSB sheathing panels bonded with liquid phenol-formaldehyde resin, complete press cycle time will be about $5^1/2$ minutes; for 3/8-inch flakeboard for webs it will be slightly shorter. For 1.5-inch-thick oriented-strand lumber the cycle time will be much longer—as much as 11 or 12 minutes depending on the resin used and the mat moisture content. Research is scheduled to quantify essential parameters controlling manufacture of oriented-strand lumber.

Closing a press to desired thickness in 30 to 60 seconds requires specific platen pressures in the range from 600 to 750 lb/in^2. An eight-opening press with platens measuring 8 by 32 feet requires 600 to 800 hp to drive hydraulic pumps and pistons adequate to achieve such closing rates.

Platen temperatures are generally in the range from 340 °F (liquid P-F resin) to 420 °F (powdered P-F resin). While it is possible to heat platens to this temperature with high-pressure steam, most plants use presses with oil-heated platens, the oil being heated with energy from combustion of wood residues. (See discussion in section 5-11.)

Blending, forming, and hot pressing are interconnected, highly automated processes, and require only a single operator per shift.

Postpressing Operations

OSB panels to be used as sheathing or floor decking (and random flakeboard for webs) are brushed to remove loose flakes as they emerge from the hot press, scanned by an ultrasonic device to detect interior delamination, and then trimmed on panel-sizing machines resembling two double-end tenoners coupled at 90 degrees to each other so that the large panels (8 by 32 feet) can be reduced to smaller size. Because specialty panels in large sizes command better prices than standard 4- by 8-foot panels, markets for large panels will be sought.

Panels of oriented-strand lumber will be ripped to conventional lumber widths before crosscutting to market lengths.

Since none of the products will exceed 32 feet in length, warehousing and shipping will be accomplished by forklift.

On each shift one person is required to operate the panel-sizing machinery and another to operate the forklift. A third person will likely be needed to perform additional postpressing operations, such as machining tongues and grooves on OSB panels for single-layer floor decking and edge profiles on webs for pole joists.

Connected Horsepower

Connected electrical motors in the flakeboard plant will total about 3,000 hp. Major contributors to this connected total are the shaping-lathe and disk flaker at approximately 500 and 600 hp, respectively; the two rotary flake dryers at about 400 hp each; flake breakers and hammermills with pneumatic transport totaling about 200 hp; and the oil hydraulic system for the hot press at about 600 hp.

Staffing

Staffing requirements in the flakeboard plant (exclusive of quality control and centralized maintenance, saw filing, and knife sharpening) should be about as follows:

Function	People per shift	Number of shifts	Total
Lead operator	1	4	4
Flaking	2	4	8
Flake drying	1	4	4
Hot pressing	1	4	4
Panel sizing	1	4	4
Other postpressing operations	1	4	4
Warehousing and shipping (forklift operator)	1	4	4
Cleanup/utility	2	4	8
Total	10		40

5-9 CENTRALIZED MAINTENANCE, SAW FILING, AND KNIFE SHARPENING

Maintenance facilities (electrical, mechanical, and carpenter) for the plant will be centralized in a shop adjacent to the steam plant (fig. 5-2). Staffing is estimated at five people per shift, 24 hours per day, 350 days per year; as four shifts are required for such continuous operation, the maintenance staff will total 20 people.

Similarly, all saw filing and knife sharpening will be accomplished in a centralized facility employing three people per shift, 24 hours per day, 350 days per year—requiring a total of 12 people engaged in these activivities.

Connected electrical motors in the maintenance shop (two cranes, air compressor, grinders, and machine tools) will total about 30 hp. The various grinding machines in the filing room will total about 25 hp.

5-10 RESIDUE FLOWS

As noted in section 3-3, residues from plant operations will total 106,390 tons annually, ovendry-weight basis. Of these residues, the pulp chips and dry planer shavings will be accumulated in bins (fig. 5-2) and sold to mills in the Missoula area. All or part of the dry flake screenings can also be sold as furnish for particleboard, depending on the fuel needs of the plant. Green hog fuel (mostly branchwood and waste from doweling operations) and stembark will be consumed in the central steam plant. Annual production of these residues should be about as follows (fig. 3-8):

Residue description	Annual production	
	Tons, ovendry basis	
Salable		
Pulp chips	6,508	
Dry shavings	14,379	
		20,887
Sometimes salable (depending on fuel needs)		
Dry flake screenings and trim		23,576
Fuel for plant consumption		
Bark	20,000	
Green hog fuel	41,927	
		61,927
Total		106,390

5-11 THERMAL ENERGY PLANT

The preponderence of fuel for the thermal energy plant originates at the delimber-debarkers (branches and bark), the dowel plant (residue from the dowel machines), and from the flakeboard plant (dry flake screenings and panel trim). The energy plant is therefore located in proximity to these sources (fig. 5-2). Adjacent space for periodic accumulation of excess fuel is indicated on the site plan.

Connected electrical motors in the furnace system will total about 325 hp and will run at about 75 percent of capacity. System circulating pumps will total about 365 hp, including standby pumps. The overall connected total will be about 690 hp.

The thermal energy plant will have one supervisor working a single shift and responsible for overall operation. Two operators will staff the plant on each of four shifts required for 24-hour operation 350 days per year.

Fuel Tonnage Required for Process Heat

All needed electrical energy will be purchased from outside sources. Heat energy required by the plant will be substantial, however, and—as noted above—this heat energy will be supplied from a thermal energy plant fueled primarily by green hog fuel and bark. Primary components of the heat requirement include energy for heating of work spaces, heating hot ponds to condition bolts entering the flakeboard plant, drying flakes, heating the OSB hot press, kiln drying half rounds to be assembled into edge-glued panels, and kiln drying flanges for fabricated joists.

Working space to be heated is about as follows:

Building	Area
	Ft^2
Administrative office	4,000
Weight-scale office	500
Shelters for delimber-debarkers	8,000
Dowel plant	15,360
Joist plant	48,150
Edge-glued panel plant (excluding kilns)	28,600
Flakeboard plant	186,000
Thermal energy plant, central maintenance shop, and central filing and sharpening room	7,200
Total	297,810

Only a few of these spaces will be heated above 50 °F; total wood requirement should not exceed 600 tons annually, ovendry-weight basis.

Energy required to hold the hot-water soak tanks at 150 °F year around can only be roughly estimated. About 141,062 tons of wood (ovendry) will enter the hot-water vats annually. This wood will contain about an equal weight of water. At 100 percent efficiency, 15,600 million Btu are required to raise this tonnage of water from an average bolt temperature of about 45 °F to about 100 °F. As the specific heat of wood is about one-third that of water, about 5,200 Btu are required to heat the wood, for a total of 20,800 million Btu annually at 100 percent efficiency. With heat losses in the vats estimated at 50 percent, and boiler efficiency at 60 percent, total Btu requirement annually should be about 20,800 million ÷ (0.5 x 0.6) = 69,333 million Btu. At 8,600 Btu content per pound of ovendry wood, this is the equivalent of the heat content of about 4,031 tons of wood annually, ovendry-weight basis.

Industrial experience has shown that direct-fired flake dryers require as much as 20 percent of the flakes (that is, screenings plus trim) to dry the remaining 80 percent of the flakes. Therefore, about 23,295 tons of fuel will be required to dry the 116,476 tons of flakes produced annually (ovendry-weight basis).

Industrial experience has also shown that bark from stems that are flaked provides sufficient heat energy to heat the hot press that forms panels from flakes. Because bark comprises about 10 percent of stem weight, this suggests that the fuel requirement to heat the flakeboard hot press should total about 11,648 tons annually, ovendry-weight basis.

About 27,541 tons of half logs will be kiln dryed annually for conversion to edge-glued panels; additionally about 23,779 tons of flange dowels will be dryed annually, for a total of 51,320 tons annually (ovendry-weight basis). About 46 percent of the energy required to kiln-dry wood is expended in evaporating the water the wood contains. If the water in the wood is equal in weight to the ovendry wood, and about 90 percent of the water is to be removed during kilning, the total annual Btu requirement will be about:

(0.9 x 51,320 x 2,000 x 1,100 Btu per pound of water evaporated) ÷ 0.46 = 220,899 million Btu annually

Because hog-fuel energy cells are only about 60 percent efficient (possibly 70 percent), fuel required annually for kiln drying must contain about 368,165 million Btu. At 8,600 Btu per pound, the annual fuel requirement for kiln drying should be about 21,405 tons (ovendry-weight basis).

The foregoing hog fuel requirements are summarized as follows:

Purpose	Annual fuel requirement
	Tons, ovendry-weight basis
Heating of working spaces	600
Heating water for flakeboard conditioning vats	4,031
Drying flakes for flakeboard	23,295
Heating flakeboard hot press	11,648
Heating dry kilns	21,405
Total	60,979

This summary suggests that, with sale of pulp chips and shavings only, there will be a significant excess of fuel (85,503 – 60,979 = 24,524 tons, ovendry, annually), creating a substantial disposal problem. Possibilities for reducing this excess include:

- Forest delimbing of the trees harvested from National Forests. At the expense of considerable labor, this would reduce incoming fuel by 20,000 tons, ovendry, annually.
- Sale of dry flake screenings to a particleboard plant; this would reduce fuel by 23,295 tons.
- Development of doweling machines to produce flakes (preferable) or pulp chips as residues when manufacturing the flange dowels; this would reduce fuel by 15,853 tons.

Another alternative would be to increase fuel consumption by addition of steam turbines driving electrical generators to supply needed power for the plant (see section 5-14).

5-12 ADMINISTRATIVE STAFF

Because most of the plant will operate 24 hours per day for 350 days per year—that is, with a four-shift schedule—four plant superintendents will be required (one for each shift). Additionally, the flakeboard plant and the joist plant will each need four shifts of a quality control person, and the edge-glued panel plant will require a quality controller for a single shift. Also, four security guards at the main gate (one per shift) will be required. Security of the truck gate will be monitored from the weight-scaling station, and thus require no additional administrative personnel. Working only the day shift, 5 days a week, will be the following additional administrative and sales staff:

Function	Number of people
General manager	1
Plant manager	1
Sales and sales engineering	6
Accounting and purchasing	1
Plant engineer	1
Personnel manager	1
Secretarial	3
Total	17

As noted in section 2-5, the procurement operation will be organized as a separate corporate subsidiary to the principal corporation. The payroll of this subsidiary corporation will be allocated to wood cost.

5-13 SUMMARY OF STAFFING REQUIREMENTS

Exclusive of procurement operations, total staff required will be about 271 people (table 5-2).

Table 5-2—Staffing required for the entire operation, exclusive of wood procurement

Plant segment or function	Personnel per shift	Number of shifts operated	Total people on payroll
Weight-scaling station	1	2	2
Portal crane	1	4	4
Debarking-merchandising	7	4	28
Doweling plant	7	4	28
Joist plant	17	4	68
Edge-glued panel plant and kilns	18	1	18
Flakeboard plant	10	4	40
Thermal energy plant supervisor	1	1	1
Thermal energy plant	2	4	8
Knife grinders and saw filers	3	4	12
Maintenance	5	4	20
Quality control			
OSB	1	4	4
Joists	1	4	4
Edge-glued panels	1	1	1
Trainees for manufacturing jobs,and to fill in for absentees	2	4	8
Security at main gate	1	4	4
Superintendents	1	4	4
General administration			
Plant engineer	1	1	1
Sales (and sales engineering)	6	1	6
Accounting (and purchasing)	4	1	4
Personnel manager	1	1	1
Secretarial	3	1	3
Plant manager	1	1	1
General manager	1	1	1
Total			271

5-14 SUMMARY OF CONNECTED HORSEPOWER IN PLANT

From the foregoing discussions, plant-connected horsepower can be summarized as follows:

Item	Horsepower
Portal crane	340
Delimbers-debarkers and merchandisers	1,200
Dowel plant	400
Kilns	1,300
Joist plant	540
Plant for edge-glued panels	925
Flakeboard plant	3,000
Thermal energy plant	690
Central maintenance shop	30
Central knife sharpening and filing room	25
Pumps for water supply	100
Total	8,550

Many, if not most, of the electrical motors in the plant will operate with intermittent loads, and most of the loads will vary during each shift. Averaged over the entire operation, the mean power demand will probably be about 60 percent of the connected load; that is, the mean power demand will average about 5,070 hp.

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CHAPTER 6: PLANT AND EQUIPMENT COSTS

CONTENTS

Plant capital costs can be aggregated by summing site acquisition and preparation costs with the costs of the various plant components, as outlined in the following sections and summarized in section 6-16. Supervisory costs of machinery suppliers during plant erection, startup, and training are included as part of capital costs—but not the payroll costs of management and workforce during these periods.

6-1 SITE ACQUISITION AND PREPARATION

A minimum of 55 or 60 acres is required for the plant (fig. 5-2), plus perhaps 10 acres separate from the plant site for disposal of refuse from the bottom of the hot-water soak tanks and for settling ponds used perhaps twice yearly to dispose of water exchanged in the soak tanks.

At this point in the analysis, when a definite site has not yet been identified, costs of site acquisition and preparation can only be approximated. Regardless of location, however, costs can be segregated as follows to permit approximation for budget purposes.

Acquisition

Ideally, a site might be located with rail siding in place—but this seems unlikely. A bare site without a siding but adjacent to the railroad so that a siding could be constructed, with access to electric power and to truck-traversible roads, and with appropriate contour and soil (and water supply) might sell for $2,000 per acre. Site cost might therefore be approximated at $140,000 (including the 10-acre disposal site).

Access Road to Site

Cost of improving (probably not constructing) an access road obviously will vary with site location. In the absence of specific site information, this cost is approximated at $15,000 per mile for 1 mile, for a total of $15,000.

Grading

Because the plant requires level terrain, only essentially level sites can be considered. If 20 days of bulldozer or grader work were required at $150 per hour, the total cost would be about $24,000.

Electrical Service

Cost of extending electrical service to the site, together with purchase of necessary transformers, is estimated at $100,000.

Water Supply

In the proposed plant, water is required for the thermal energy plant (some steam generation), for summer sprinkling of the log deck under the portal crane, for blending with resins to prepare adhesive binders, for replenishing the hot-water soak tanks, for toilets in the various plant components, and for drinking and washing. In most of the locations under consideration, all but potable water should be available from the Kootenai River. A well will be required for potable water.

The thermal energy plant will have a closed-loop water system to the extent practical.

Development of a potable-water well is estimated to cost $10,000. A pumping station to withdraw river water is estimated to cost $25,000. The total is therefore approximated at $35,000. (The budget for the thermal energy plant includes some additional funds for development of the water supply; see also section 6-14 for the sprinkler-system budget.)

Sewage and Waste-Water Disposal

Sewage from the various plant buildings will be disposed of in septic tanks—probably five in all. Construction of these septic tank systems should cost about $14,000. Waste water will come primarily from the resin mixing centers in the OSB plant and the joist plant, and from the hot-water soak tanks. Also, there will be some runoff from summer sprinkling of the log deck.

As noted previously, the water from the hot-water soak tanks (when it must be replaced) will be pumped out and transported to settling ponds at some distance from the plant site; tank sludge will be removed by front-end loaders and also transported to the disposal site. Similarly, the waste water from the resin mixing centers will be contained and transported to the settling ponds. The cost of holding tanks for the waste water from the resin mixing centers, and preparation of the settling ponds is estimated at $15,000.

The total for this segment of cost should therefore be about $29,000.

Storm Drains

Storm drains directing rain water are estimated to cost about $15,000.

Railroad Siding

A minimum of 2,200 feet of rail siding must be constructed, with two crossings of a truck-loading road (fig. 5-2). Installed cost of treated crossties with hardware will be about $34 per tie; if installed with 21¼-inch spacing, about 1,242 ties will be required, yielding an installed cost of about $42,000 plus the cost of rails. Total cost of the siding is approximated at $60,000.

Interior Roads

About 10,000 feet of roads are required within the plant perimeter (fig. 5-2). At a cost of $15,000 per mile these roads will cost about $28,000.

Paving

A few of the high-traffic areas for forklift operation will be paved; $30,000 is allotted for this purpose.

Perimeter Fences, Gates, and Guardhouse

Perimeter chain link fencing (6 feet high with three strands of barbed wire on top) needed will total about 6,400 feet. Two gates will also be needed, each with a remotely controlled barrier bar. At $6 per lineal foot of fence including the cost of the gates, and $2,000 per barrier bar, the total fencing cost should be about $42,000. The guardhouse is estimated to cost $4,000, giving a total for fencing and guardhouse of $46,000.

Summary

Estimated site acquisition and preparation costs are summarized as follows:

Item	Cost
Acquisition	$140,000
Access road to site	15,000
Grading	24,000
Electrical service (transformers owned by plant)	100,000
Water supply	35,000
Sewage and waste-water disposal	29,000
Storm drains	15,000
Railroad siding	60,000
Interior roads	28,000
Paving	30,000
Perimeter fences, gates, and guardhouse	46,000
Total	$522,000

6-2 PORTAL CRANE

Installed cost of the portal crane (figs. 5-1 and 5-2) is comprised of several elements, as follows:

Item	Estimated cost
Site profiling, compaction and drainage	(Covered in previous paragraphs)
Machinery (the portal crane)	$1,360,000
Erection	200,000
Freight	50,000
Rail installation	325,000
Portable sprinkler system for log deck	10,000
Total	$1,945,000

The foregoing costs include supervision by the manufacturer during erection, startup supervision, and training of the crane operators.

6-3 DELIMBERS-DEBARKERS AND MERCHANDISERS

It is difficult to estimate the installed cost of the delimber-debarker and merchandiser layout as diagramed (fig. 5-3) because it is a departure from previously built merchandisers—that is, it calls for handling whole trees of small diameter through delimbers coupled to debarkers, and then segmenting these stems to maximize their value.

A senior consulting engineer experienced in designing tree merchandisers estimates that the complete layout installed (fig. 5-3), with required engineering, building, startup supervision, and spare parts, will cost $6.5 to $7.5 million, of which nearly $3 million is assigned to development and construction of the two merchandisers. For budget purposes, the cost is estimated at $7 million. Additionally, $150,000 will be needed to purchase a forklift designed for rapid handling of log segments from the point of discharge from the merchandiser to the dowel plant, kilns, and flakeboard plant. Thus the total cost is estimated at $7,150,000, including pulp-chip loading facilities and a conveyor to move residue (hogged limbs and bark) to the thermal energy plant.

6-4 DOWEL PLANT

Cost of the dowel plant (fig. 5-7) can be estimated from the sum of its components, as outlined in the following paragraphs.

Building

The dowel plant will have about 15,360 ft^2 under roof. No overhead cranes or exceptionally high clearances are required. Dowel machines will be installed at more-or-less ground level, with residue conveyors somewhat below ground level. Except for the tree-prop pointer and chamfer machines, no blowpiping is required. During winter, the building will likely be heated to about 50 °F. With the foregoing in mind, it should be possible to construct the building for about $20/ft^2, or about $307,000.

Machinery Groups

Doweling machines are available locally in Montana (Bouma), or from West Germany (Bezner). With infeed and outfeed conveyors, switch cabinets, cutterheads, tools, and accessories (but not with log decks or grading chains), the machines can be purchased for about $60,000 to $96,000 each depending on manufacturer and machine size. For the five machines needed, the average should be about $78,000, for a total of $390,000.

The tree-prop pointer and top chamfering machine can be constructed for a total of about $10,000, including cutterheads and starting switches.

Structural Steel, Sheet Metal, and Piping

This equipment grouping includes five two-section infeed log decks and a grading chain, all estimated to cost about $55,000 installed.

Inplant conveyors collecting residue from the dowelers will cost about $15,000, and the blowpipe system for the pointing and chamfering machines will cost about $3,000. Additionally, a long residue conveyor is needed to transport residues to the thermal energy plant; this conveyor is estimated to cost $20,000.

All of the foregoing items under this heading total $93,000.

Machine Foundations and Installation

Foundations for machines and conveyors, and their installation on the foundations, are estimated to cost $25,000.

Spare Parts

Spare parts for the dowelers, the tree-prop pointer and chamfering machines, and the conveyors will cost about $25,000.

Electrical Service (Supplemental to Machinery Groups)

From tranformer pole to machine and conveyor switchgear supplied with the machines, dowel plant electrical service costs will be about $5,000.

Engineering

Engineering design costs are estimated at 4½ percent of all of the foregoing, that is, 0.045 x $855,000, or about $38,000.

Supervision (by Machine Manufacturers)

Erection—Supervision by the machine manufacturers should not be necessary during erection of the dowel plant.

Startup—The manufacturer of the dowel machines should provide startup services as part of the purchase price.

Training—Extended training, beyond the startup period, should not be needed in the dowel plant.

Summary of Costs

Total estimated cost of the dowel plant is as follows:

Item	Cost
Building	$307,000
Machinery groups	400,000
Structural steel, sheet metal, and piping	93,000
Machine foundations and installation	25,000
Spare parts	25,000
Electrical service	5,000
Engineering	38,000
Supervision by machine manufacturers	0
Total	$893,000

6-5 KILNS

Dowel Kilns and Kiln Pallets

As noted in section 5-6 and figure 5-9, two dowel kilns each 100 feet long, about 22 feet wide, and with space for loads up to 12 feet high are required for the primary drying job. Additionally, a redry room of the same dimensions is required for those dowels not sufficiently dry to pass moisture-content inspection on entry to the joist plant (fig. 5-8). Erected cost of these three steel-frame aluminum-panel kilns with all heating coils, controls, fans, motors, and spares—and including startup supervision by the manufacturer— is estimated to total $600,000.

Validation of drying schedules is budgeted at $20,000.

As previously noted, a working inventory of dowel pallets should number about 500. At a cost per pallet of $100, the total acquisition cost of the 500 pallets should be about $50,000.

Kilns for Half Cylinders and Studs

As noted in section 5-7 (see also fig. 5-9), five double-track kilns each measuring about 75 feet long, with width and height sufficient to accommodate kiln loads 6 feet wide and 12 feet high, are needed to dry half cylinders and studs. Each of these five kilns will cost about the same as the dowel kilns, that is, $200,000 each for a total erected cost of $1 million including spare parts and startup supervision.

Cooling Sheds

Also needed are eight cooling sheds each equal in length to the corresponding kiln (fig. 5-9), for a total of 14,000 ft^2. At $10/$ft^2$, total shed price (erected) should be about $140,000.

Summary of Costs

Total estimated cost of the kilns, dowel pallets, and cooling sheds is summarized as follows:

Item	Cost
Dowel kilns	$ 600,000
Validation of drying schedules	20,000
Dowel pallets	50,000
Kilns for half cylinders and studs	1,000,000
Cooling sheds	140,000
Total	$1,810,000

Included in this total are the transfer cars and tracks (fig. 5-9), but not the stacker and unstacker, which are costed as part of the plant for edge-glued panels.

6-6 JOIST PLANT

Building

The joist plant (fig. 5-8) will have about 48,150 ft^2 under roof. Some long spans are required, as is a craneway adjacent to the loading dock. Blowpipes to remove sawdust and shavings from the finger-jointing machines, dado moulder, double-end trim saw, and hog for trim ends will be required. During winter the building will likely be heated to about 55 °F.

With the foregoing in mind, building costs are estimated at $23/$ft^2$, or about $1,107,000.

Machinery Groups

Primary machine costs are estimated as follows:

Machine	Cost
Conveyor incorporating moisture content and MOE evaluation, and end and defect trim	$100,000
Four-station finger joint and curing operation	400,000
Tension proof tester	20,000
Dado moulder	150,000
Joist assembly machine	150,000
Double-end trim saw machine	10,000
Joist flexure test machine	15,000
Strapping machine	20,000
Crane over storage and shipping area	25,000
Inplant forklift	20,000
Air compressor	5,000
Quality control equipment	10,000
Total	$925,000

Structural Steel, Sheet Metal, and Piping

Conveyor chains and drives not listed under the previous heading, structural steel, sheet metal, and piping, are estimated to cost $70,000.

Machine Foundations and Installation

Machine foundations and installation of the machines and conveyors on their foundations will cost about $50,000.

Spare Parts

At 5 percent of the cost of machinery plus structural steel, sheet metal, and piping, spare parts will cost about $50,000.

Electrical Service

From transformer pole to machines and conveyor switchgear supplied with the machines, joist plant electrical service costs will be about $15,000.

Engineering

Engineering design costs are estimated at 4½ percent of all the foregoing, that is, 0.045 x $2,217,000 or about $100,000.

Additionally, $75,000 is budgeted for intensive engineering assessment and selection of equipment to finger-joint and glue-cure the joist flanges, equipment to machine the joist flanges and webs, and equipment and adhesives to fasten joist flanges to the webs.

The engineering budget for the joist plant therefore totals $175,000.

Supervision (by Machine Manufacturers)

Erection—Supervision by the machine manufacturers during erection should be minimal, perhaps totaling $10,000.

Startup—The manufacturers of the major machines should provide primary startup services as part of the purchase price. Some extended startup services may be needed, however, so $20,000 is budgeted for this purpose.

Training—Some employee training will be needed in moisture content and MOE determination, finger joint cutterhead grinding and setup, tension proof testing, dado moulder setup and maintenance, joist assembly, and joist flexure testing; $30,000 is budgeted for this training.

Summary of Costs

Total estimated cost of the joist plant is estimated as follows:

Item	Cost
Building	$1,107,000
Machinery groups	925,000
Structural steel, sheet metal, and piping	70,000
Machine foundations and installation	50,000
Spare parts	50,000
Electrical service	15,000
Engineering	175,000
Supervision by machine manufacturers (erection, startup, and training)	60,000
Total	$2,452,000

6-7 PLANT FOR EDGE-GLUED PANELS

Building

Excluding the kilns, the plant for edge-glued panels (fig. 5-9) has 28,600 ft² under roof. The area housing the unstacker and panel manufacturing facility will be heated in winter to perhaps 55 °F. At the infeed end of the plant, only the kiln lead operater's office and the operators' stations for the twin bandsaw and the kiln stacker will be heated—likely by radiant heaters. Heat from the kilns will also ameliorate winter temperatures in the bandsaw area.

No overhead cranes or exceptionally high clearances are required. The bandsaw will be elevated somewhat to permit servicing and to provide clearance for a sawdust conveyor leading to a hog-fuel bin. The balance of the equipment will be installed more or less at ground level, with only sufficient elevation to provide convenient working levels at the various sorting chains. A blowpipe system will remove shavings and sawdust from the blanking planer, moulder, panel cutoff saw, and panel rip and crosscut saws and deliver these residues to the adjacent shavings loading station (fig. 5-2). Dust from the panel sander will probably be piped to the fuel bin, as it has little potential as particleboard furnish and therefore should not be discharged to the shavings bin.

With the foregoing in mind, building cost is estimated at $20/ft², or about $572,000.

Machinery Groups

Primary machine costs are estimated as follows:

Machine	Cost
Twin bandsaw with infeed chain and offbearing belts	$ 130,000
Kiln stacker	70,000
Kiln unstacker	70,000
Blanking planer and matcher (used Stetson-Ross 6-10A1 or used Yates A-66 motorized planer and matcher with bottom head cutting first under a yielding holddown)	60,000
Stacker behind blanking planer	15,000
Moulder	75,000
R/F edge gluer with flying cutoff saw	160,000
Panel stacker	10,000
Double-decker panel sander	75,000
Panel multiple ripsaw	120,000
Panel multiple crosscut saw	120,000
Panel stacker	10,000
Conveyors including:	60,000
Infeed and outfeed decks to twin bandsaw	
Infeed deck to stacker	
Stick-return conveyor to stacker	
Infeed and outfeed conveyers for blanking planer	
Outfeed roll case for panel press	
Air compressor	5,000
Inplant forklift	20,000
Total	$1,000,000

Structural Steel, Sheet Metal, and Piping

The blower system to remove dry sawdust and shavings from panel manufacturing operations and the shavings bin (for truck loading) are estimated to cost $60,000. The green-sawdust conveyor from the bandsaw, the sander-dust blowpipe, and the fuel accumulation bin holding these two residues is estimated to cost $20,000.

Structural steel and sheet metal not previously tabulated is estimated to cost about $15,000.

Machine Foundations and Installation

Machine foundations and installation of machines and conveyors on the foundations are estimated to cost $55,000.

Spare Parts

At 5 percent of the cost of machinery groups plus structural steel, sheet metal, and piping, spare parts will cost about $55,000.

Electrical Service

From transformer pole to machines and conveyor switchgear supplied with the machines, electrical service to the plant for edge-glued panels will cost about $15,000.

Engineering

Engineering design costs are estimated at 4½ percent of all the foregoing, that is, 0.045 x $1,792,000, or about $81,000.

Additionally, $30,000 is budgeted for intensive assessment and evaluation of jointing and edge-gluing equipment.

The engineering budget for the edge-glued panel plant therefore totals $111,000.

Supervision (by Machine Manufacturers)

Erection—Supervision by the machine manufacturers during erection should be minimal, perhaps totaling $10,000.

Startup—The sellers of the major machines should provide startup services as part of the purchase price. Some extended startup services may be required, however, so $20,000 is budgeted for this purpose.

Training—Some employee training will be needed in machine setup of the twin bandsaw, blanking planer, moulder, panel press, double-decker sander, and panel cutup machines; $30,000 is budgeted for this training.

Summary of Costs

Total estimated cost of the plant for edge-glued panels is estimated as follows:

Item	Cost
Building	$ 572,000
Machinery groups	1,000,000
Structural steel, sheet metal, and piping	95,000
Machine foundations and installation	55,000
Spare parts	55,000
Electrical service	15,000
Engineering	111,000
Supervision by machine manufactures (erection, startup, and training)	60,000
Total	$1,963,000

6-8 ORIENTED-STRAND BOARD PLANT

Estimation of the cost of the plant to make oriented-strand panels and lumber can be approached by summing the cost of components based on current costs of machinery groups. An alternative method, probably equally serviceable, is estimation based on what comparable plants have cost to build within the last few years. For lack of better information, the latter approach is used in this section. Because site acquisition, and log scaling, storage, and debarking are costed in sections 6-1 and 6-2, these costs are not included in the cost of the OSB plant. Also, the thermal energy plant, central maintenance shop, central knife sharpening and filing room, general office, and plant sprinkler system are costed in sections 6-9 through 6-14; these costs are therefore not included in the following estimate of the OSB plant.

Recently, stand-alone OSB plants of about the capacity of the one contemplated here have been built elsewhere in the United States at costs from $20 to $40 million. Considering the major plant elements noted in the previous paragraph that have been costed separately, it seems reasonable to estimate the erected cost of the OSB plant itself (fig. 5-11) at $30 million, including manufacturers' supervision during erection, startup, and training.

6-9 THERMAL ENERGY PLANT

Installed cost of the thermal energy plant, including startup and operator training, is estimated at $3,400,000.

6-10 CENTRAL MAINTENANCE SHOP

The central shop (fig. 5-2) is charged with maintenance of buildings, fixed machinery, and rolling stock within the plant. It therefore must be equipped not only for carpentry, welding, plumbing, and machining, but also for sheet metal, hydraulic, and electrical work.

It is projected to measure 40 by 60 feet (2,400 ft^2). Because of its provisions for comfortable working temperatures in winter, overhead cranes, pits for maintenance of forklifts, and cabinetry for storage of tools and supplies, the clear-span structure is estimated to cost about $40/$ft^2$ or $96,000.

Equipment needed to conduct the maintenance work is budgeted at $60,000. Additionally, two vehicles (probably pickup trucks) dedicated to the maintenance crews will be required, with estimated cost of $36,000.

Total estimated cost of the maintenance facility is therefore $192,000.

6-11 CENTRAL KNIFE SHARPENING AND FILING ROOM

The knife sharpening and filing room will be responsible for the tooling in all the machine centers throughout the plant. Thus knives for residue chippers, primary flaker, the shaping lathe, dowel machines, planer-matchers, moulders, and finger jointers must be sharpened, as well as bandsaws and a great variety of circular saws.

The clear-span building—which will be heated to about 65 °F in winter—will measure 30 by 60 feet (1,800 ft^2) and is estimated to cost about $20/$ft^2$, or $36,000. Equipment for knife and saw sharpening is budgeted at $75,000. Also, two small utility vehicles dedicated to use by the crew operating the facility are budgeted at $20,000.

The estimated total cost of the facility is therefore $131,000.

6-12 WEIGHT SCALE

Logs on incoming trucks will be weight-scaled near the entry gate (fig. 5-2). Installed cost of a 70-foot platform scale (60-ton capacity) is estimated at $36,000. The 500-$ft^2$ office for the scale operator will cost about $15,000, yielding a total cost of $51,000.

6-13 GENERAL OFFICE

The general administrative office will have 4,000 ft^2 under roof, estimated to cost $40/$ft^2$, or $160,000. Furnishings and communications and computer equipment will cost another $40,000, yielding a total cost of $200,000.

6-14 SPRINKLER SYSTEM FOR ALL BUILDINGS

As noted in section 5-11, the entire plant will have 297,810 ft^2 under roof. All of this roofed area will be provided with sprinklers designed to reduce loss from fire. The installed cost of this entire sprinkler system is estimated as follows:

Item	Cost
40,000-gal underground water tank, installed	$ 20,000
Pumping unit with capacity of 1,000 gal/min with motor and controllers	19,000
Underground piping from water source to tank and to various buildings	40,000
Hydrants (10 at $1,500 each)	15,000
Within-building risers and sprinkler system, at $1.25/$ft^2$ x 297,810 ft^2	372,000
Total	$466,000

6-15 CONTINGENCIES DURING CONSTRUCTION

A contingency fund of 5 percent of all of the foregoing costs is budgeted, that is, 0.05 x $51,175,000 or $2,559,000.

6-16 SUMMARY OF PLANT AND EQUIPMENT COSTS

From sections 6-1 through 6-16, plant and equipment costs can be summarized to total $53,738,000 as follows:

Item	Amount
Site acquisition and preparation	$ 522,000
Portal crane	1,945,000
Delimbers-debarkers and merchandisers	7,150,000
Dowel plant	893,000
Kilns	1,810,000
Joist plant	2,452,000
Plant for edge-glued panels	1,963,000
OSB plant	30,000,000
Thermal energy plant	3,400,000
Central maintenance shop	192,000
Central knife sharpening and filing room	131,000
Weight scale	51,000
General office	200,000
Sprinkler system for all buildings	466,000
Contingencies during construction	2,559,000
Total	$53,734,000

Purchase of the expensive feller-bunchers, forwarders, log trucks, and support equipment required for harvesting will be the responsibility of individual logging contractors, rather than the responsibility of the procurement corporation. Such purchases should be possible for the contractors because they will have in hand substantial contracts from the procurement corporation to deliver wood to the parent corporation. With each feller-buncher (and matching forwarder) harvesting about 218,000 trees per year, approximately 11 such machine teams will be required to harvest the 2,456,972 trees (110,000 tons of stemwood, ovendry) scheduled annually from National Forest lands.

CHAPTER 7: ESTIMATES OF CAPITAL REQUIREMENTS, OPERATING COSTS, AND BUSINESS ASSUMPTIONS UNDERLYING THE FEASIBILITY ANALYSIS

CONTENTS

7-1 PLANT LIFE

In section 2-3 under "Summary of Available Resource," it was assumed that over a 20-year plant life an annual harvest of 110,000 tons of sub-sawlog-size and dead timber would utilize 52 percent of such wood available on slopes of less than 56 percent in the National Forests within the Libby-Troy procurement area (mostly within a road radius of 75 miles); these data were based on 1986 information and assumed no growth during the 20-year period.

While the initial assumptions contemplated a 20-year plant life, it seems likely that with more-or-less continuous adjustments to meet changing resources, plant life could be extended indefinitely.

At the outset it seems unlikely that all of the remaining 48 percent of such undesirable (to conventional processors) lodgepole pine will be harvested by competitive operations. Moreover, in 20 years technology should be available to economically harvest such wood on slopes steeper than 55 percent—a resource not considered in the discussions in chapter 2. With annual harvest and regeneration of 2,000 or 3,000 acres of lodgepole pine annually (commencing with initiation of plant operation), the first of these acres regenerated should carry pines suitable for doweling 40 years from plant startup. When 40 years have passed from the first regeneration, therefore, ample wood supplies should be available to the plant.

Purchased wood of sawlog diameter—but perhaps not of sawlog quality—should continue to be available indefinitely at the level of 90,000 tons per year proposed in chapter 2 for the first 20 years of plant operation.

In summary of these introductory comments on plant life, it seems unlikely that the plant will cease operations after 20 years. For the purposes of this analysis, however, it is assumed that the plant will operate for 20 years, preceded by a 2-year preproduction development and construction period.

7-2 PLANT AND PREPRODUCTION COSTS

The proposed plant will cost an estimated $53,734,000 (including the 5 percent contingency allowance noted in chapter 6), comprised of the following components as described in section 6-16:

Site acquisition and preparation	$ 548,000
Portal crane	2,042,000
Delimbers-debarkers, merchandisers	7,508,000
Dowel plant	938,000
Kilns	1,901,000
Joist plant	2,575,000
Edge-glued panel plant	2,061,000
OSB plant	31,500,000
Thermal plant	3,570,000
Maintenance shop	202,000
Sharpening and filing room	137,000
Weight scale	53,000
General office	210,000
Sprinkler systems	489,000
Total	$53,734,000

In addition to these costs, the project requires building a log and raw materials inventory before beginning production, hiring management and sales personnel, and employing some key production workers during the preproduction period. These expenditures are estimated (see section 7-4) as follows:

Sales costs	$ 438,000
Log inventory and materials	1,375,000
Labor costs	1,128,000
Total	$2,941,000

Because the return on investment varies as the project's financing varies, two analyses were made of cash-flow and return on investment. The first used an equal mix of debt and equity to fund the project. This approximates the median of debt-to-equity ratios of publicly traded forest products firms operating in Montana. In this first analysis, additional costs associated with assumed project financing include those for underwriting, and legal and

accounting fees needed to develop long-term financing for the project—estimated at $1,663,000. Preproduction costs also include interest ($2,797,000) on the construction loan of $61,134,000.

The second analysis evaluated the project independently from the specific financing approach; that is, only the cash-flows necessary to develop the project and those derived from its operation were considered—no cash flows associated with financing were considered. The results of both of these analyses are displayed in chapter 10.

Timing of all expenditures is discussed in the following paragraphs.

7-3 CASH EXPENDITURES FOR THE PREPRODUCTION PERIOD

The preproduction period will last 2 years, but the costs just outlined in section 7-2 will not be incurred evenly throughout the 2-year period. During the first 10 months, half of the engineering and supervision costs are assumed to be incurred. The remaining engineering and supervision costs are assumed to be incurred ratably throughout the next 14 months. Building, equipment, and machinery costs are assumed to be incurred ratably during the second year. Spare parts and vehicles are assumed to be purchased during the last month of the 2-year period. Land is purchased during month 11 of the projection, and site preparation costs are assumed incurred during month 12.

Underwriter's fees will be paid at the start of year two. Legal and accounting fees will be paid monthly during year two. Some recurring operating expenditures, such as raw material purchases, labor costs, supplies, and sales costs, will be made in the preproduction period—as described in the following paragraphs.

7-4 OPERATING COSTS

As previously noted, the plant will begin production at the start of year 3. Some operating costs will be incurred prior to production; these costs are discussed in the balance of this section.

Raw Material Costs

The raw materials used by the facility are stemwood, resin for OSB, and adhesives for assembly of fabricated joists and edge-glued panels.

This analysis assumes that stemwood will be purchased beginning in month 23. In month 23, 75 percent of the monthly costs will be incurred. In month 24 and all subsequent months, a full month's stemwood will be purchased. The cost of stemwood purchases during the preproduction period will be about $1,300,000. By month 27 a full 3 months' stemwood will be on hand and maintained throughout the life of the plant. The stemwood inventory will be processed to zero during the last 3 months of the last operating year.

Included in the stemwood cost is an allowance for procurement administration. As discussed in chapter 2, it is assumed that the procurement operation will be undertaken by a separate corporation. The costs of this operation (2.6 percent of stemwood costs) have therefore been included in the cost of the stemwood. If the procurement operation were handled by the plant itself, the costs associated with procurement could be allocated to other expense and asset categories such as labor costs, supplies, and vehicles, but such allocation would not materially affect the financial analysis.

Other materials are assumed to be purchased the month before they are used based on the projected production levels of the upcoming month.

In month 24, 25 percent of a full month's inventory of material other than stemwood will be purchased. The costs of these other materials in the preproduction period will be about $75,000. In months 25 and 26, the amount of material will increase to 50 and 75 percent, respectively, of quantities needed for full production. In all subsequent months, costs will be based on full production. A 1-month inventory of materials other than stemwood will be maintained through the life of the plant, and will be processed to zero during the last month of the last operating year. Annual costs for all raw materials follow:

Stemwood	$ 8,910,000
OSB resin	2,573,000
OSB wax	378,000
Joist adhesive	430,000
Flange finger joint adhesive	71,000
Edge-glued panel adhesive	161,000
Total	$12,523,000

Labor Costs

Labor costs include those for supervisory, management, and plant labor forces. Management labor begins in month 1 of the preproduction period, supervisory labor begins in month 18, and lead plant labor begins in month 21. Labor costs include salaries and fringe benefits. The monthly labor costs for periods comprising the first 2 years are as follows:

Months 1-12	$ 18,500
13-18	32,500
19-21	81,000
22-24	156,000

The total for year 1 will be $222,000, and for year 2, $906,000. At full production the total labor cost of operating the plant will be $8,672,000 (an average of $32,000 for each of the 271 employees). The assumption is that the plant will attain full production by month 4 of year 3. Labor costs for the first year of operation will be $7,588,000. As noted above, each subsequent year's labor cost will be the base $8,672,000, adjusted for inflation.

Supplies and Services

Purchases of supplies and services consumed by the plant (exclusive of stemwood, adhesives, and wax), and of contracted services for repairs and maintenance are estimated at 1.5 percent of initial plant and equipment costs in the first year of operation, and 3 percent of initial plant and equipment costs, adjusted for inflation, for subsequent years.

Sales Costs

Sales costs incurred in marketing the various products of the operation are estimated at $875,000 annually, as follows:

Travel	$100,000
Telephone	25,000
Advertising	500,000
Miscellaneous	250,000
Total	$875,000

These expenditures are made each month beginning in month 19. Because revenues are estimated on a net f.o.b.-mill basis, cash discounts and wholesalers' commissions are not included in this tabulation of sales expense.

Sales costs for the preproduction period are estimated at $438,000.

Professional Services and Insurance

Expenditures for professional services include fees for outside auditors and legal fees. These expenses will be incurred beginning in year 3, and are estimated to total $110,000 annually.

Based on discussions with a major insurance company covering a number of large wood products facilities, estimated annual fire and liability insurance costs will be $500,000 to $750,000. A cost of $625,000 was used in the analysis.

Property Taxes

Property taxes for the proposed facility in Lincoln County were estimated with the help of Robert Holliday, Montana Department of Revenue, Property Tax Division. These estimates indicate that the tax bill should range from $800,000 to $1,200,000 per year. Property taxes cannot be estimated precisely, however, until the exact site location is known. A base figure of $1 million was used to estimate the annual property taxes.

Portions of the property tax can be waived on new Montana businesses. The most attractive waiver appears to be one that allows for the reduction of a portion of the tax, at local option, for the first 10 years of a new project. It was assumed that this local tax reduction would be obtained, and that the taxes would be as follows starting in the first year of production:

Production year	Annual property tax
1	$500,000
2	500,000
3	500,000
4	500,000
5	500,000
6	550,000
7	600,000
8	650,000
9	700,000
10-20	750,000

In the analyses, these costs were adjusted for inflation.

Utilities

Utility costs consist primarily of the cost of electrical energy to run the plant and its machinery. They will begin at the start of year 3, and are estimated at $1,491,000 per year.

Vehicles

Vehicles will be purchased at the start of the production period, and replaced every 5 years. Total cost of initial vehicle purchases is $59,000 (two vehicles each for the maintenance shop and the central knife sharpening and filing room, including contingency allowance).

7-5 PREPRODUCTION FINANCING

The plant's projected financing includes a construction loan for the first 2 years of the project. No payments on this loan will be made until the plant is finished and the company has sold a bond issue and sold stock to investors.

The construction loan will be a credit line established in the project's first month. The company will draw upon this line monthly to meet cash needs for construction and working capital until the project achieves a positive cash-flow. Interest will accrue monthly at an annual rate of 10 percent.

Interest costs during construction are assumed to increase the cost of plant construction; therefore, for the purposes of this projection, they will be capitalized and allocated with 20 percent to buildings and 80 percent to equipment. These amounts will be added to the depreciable basis of the project.

7-6 LONG-TERM FINANCING

The construction loan will be paid off at the end of year 2 with proceeds of a stock sale and bond issue undertaken during year 2. For this projection it is assumed that all the funds from these financing efforts, less the amount of the construction loan and preproduction costs, will be available at the end of year 2 as working capital for the initial production period.

Sales of stocks and bonds to investors will each provide $31 million, for a total of $62 million. Underwriter fees to be paid during the first month of year two will be $930,000 for the stock sale and $233,000 for the bond sale.

Accounting and legal expenses related to the issue of stocks and bonds are estimated at $500,000, divided equally between the stocks and the bonds. All expenses relating to the bond issue are capitalized and amortized over the life of the bonds. Fees relating to the stock issue are not deductible for tax purposes.

The bonds will have a 20-year life; the interest rate is assumed to be 10 percent. The bonds will be paid off in equal installments, 6 months apart, with the first payment to be made in the sixth month of the third year. This semiannual payment will be $1,807,000.

7-7 REVENUE

As described in section 3-3, estimated annual net sales with the plant operating at full production (100 percent of rated capacity) will be $38,197,000. It is assumed that the plant will have achieved full production and sales by month 4 of the first year of production. Estimated net sales revenue in this first year is $33,420,000. For subsequent years it is assumed that revenue will be $38,197,000 adjusted by the appropriate inflation rate.

7-8 DEPRECIATION

For purposes of this projection, tax depreciation is assumed to equal accounting depreciation. Tax depreciation methods follow the modified accelerated cost recovery system (MACRS) methods required by the 1986 Tax Reform Act. All depreciation begins at the first month of year 3, with depreciable lives according to MACRS ranging from 5 to 31.5 years.

7-9 INFLATION FACTORS

Revenue is assumed to increase by 4.5 percent per year, based on Wharton Econometrics long-term forecasts for prices of lumber and wood products for the period 1988-2007 (Wharton 1987).

Expenses subject to inflation are assumed to increase by 3.6 percent per year, based on Wharton Econometrics forecasts for the Producer Price All-Commodities Index. The expenses considered subject to this inflation factor are raw materials, labor, supplies and services, sales costs, professional services, property taxes, utilities, and vehicles.

7-10 ACCOUNTS RECEIVABLE

Revenues are assumed to be collected in the month after they are earned. Accounts receivable are therefore assumed equal to 1 month's sales. For cash-flow and tax purposes the amounts in the accounts receivable balance are one-twelfth of the current year's sales.

7-11 TAX RATE

The applicable income tax rate is assumed to be 40.75 percent, including both Federal and State levies.

7-12 LIQUIDATION

For the purposes of this projection (see the introductory paragraph in this chapter for comments on plant life), it is assumed that assets are sold or written off at the end of year 22 (production year 20). The land's sale value will be its cost, increased by the projected change in the Producer Price All-commodities Index. Depreciable assets will be written off, creating a tax benefit. Raw-material inventories will be utilized in the operation's last months.

7-13 REFERENCE

Wharton Econometrics Forecasting Associates. 1987. U.S. long-term forecast annual model. Bala Cynwyd, PA: Wharton Econometrics Forecasting Associates: 1-87.

CHAPTER 8: SHIPPING COSTS

CONTENTS

Potential plant sites are on the Burlington Northern main east-west rail line, and adjacent to U.S. Highway #2 in the Libby-Troy area. The Union Pacific rail system can be accessed a few miles west at Moyie Springs, ID, or more distantly in Butte, MT (figs. 2-4, 2-5, and 8-1). For rail access to the Butte connection with the Union Pacific, transfer of cars from the Burlington Northern for a short intermediate haul via Montana Rail Link—a several-hundred-mile rail line through southern Montana recently severed from Burlington Northern—is required from Sandpoint, ID, to Butte; alternatively, wood can be truck-hauled to Moyie Springs for loading on the Union Pacific line, or truck hauled to Noxon, MT, for shipment via Montana Rail Link to the Union Pacific connection at Butte.

The Interstate Highway System (fig. 8-2) is most conveniently accessed at Spokane, WA, Missoula, MT, or Shelby, MT. Major markets are, for the most part, distant from northwestern Montana (table 8-1).

The nearest salt water port is Seattle, WA—439 miles from Libby. A barge-loading facility, with access to the Pacific, is located in Lewiston, ID, at the head of navigation on the Snake River and 263 highway miles from Libby.

8-1 TRUCKING COSTS

Since deregulation, the cost of trucking wood products to market has diminished; while these costs can be estimated (table 8-1), the actual cost can be determined only by negotiation for a particular hauling contract.

In general, however, truck transport to most western and southwestern markets is competitive with rail transport—particularly to customers not located on a rail siding (table 8-1). Additionally, truck transport affords prompter delivery than is usually possible by rail. Truck delivery also provides a mechanism for minimizing inventories in distributing yards because trucks typically have a net load of only 25 tons, and the cargoes can readily be offloaded at two or more locations, whereas rail cars typically carry 40 to 90 tons of cargo and are less conveniently delivered to more than one customer.

8-2 RAIL TRANSPORT COSTS

Because the projected plant location is on the Burlington Northern rail line, virtually all rail shipments will move via Burlington Northern. On this line, all of the commodities the plant will produce are subject to the same tariffs. These published tariffs for boxcar shipments (table 8-1) are typically higher than the rates achieved through haul contract negotiation; for ease of reference, 25 percent reductions in the published tariffs are tabulated (table 8-1).

The fabricated joists, which will usually be rail shipped in 64-foot lengths, will move on flatcars rather than in boxcars, but the rate will probably not be appreciably different.

For the distant markets in the South and Southeast, lower published tariffs apply if shipments are made in 40-foot containers via rail piggyback, as follows:

Destination	Dollars per ton
Atlanta	94
Houston	88
Jacksonville	110
Memphis	82
Miami	127
New Orleans	95

The minimum weight per container is only 40,000 pounds. In addition to the published tariff tabulated above, however, there is a $4 charge per container to load and unload it.

Two by four studs, which comprise only a small portion of the plant output (about 4 million bd ft annually), might be shipped via the Union Pacific rail line in Moyie Springs, ID. Union Pacific rates for boxcars or flatcars are particularly favorable to the Salt Lake City market area ($26/ton published tariff with estimated $20/ton contract price per ton). The cost of truck transport from the plant site to Moyie Springs would add an additional $2 or $3/ton to the shipping cost of the studs.

8-3 COST OF WATER-BORNE SHIPMENT

Three destinations are of particular interest when considering water-borne shipments: Los Angeles, Osaka, and Shanghai.

It seems unlikely that wood products could be trucked from the Libby-Troy area some 263 miles to the Snake River, loaded on barges and floated to salt water, and then transloaded to oceangoing ships at a price competitive to trucking the 439 miles to Seattle for direct loading onto oceangoing vessels. When oceangoing ships can be direct-loaded at Lewiston, ID, Snake River transport to salt water may be competitive, however.

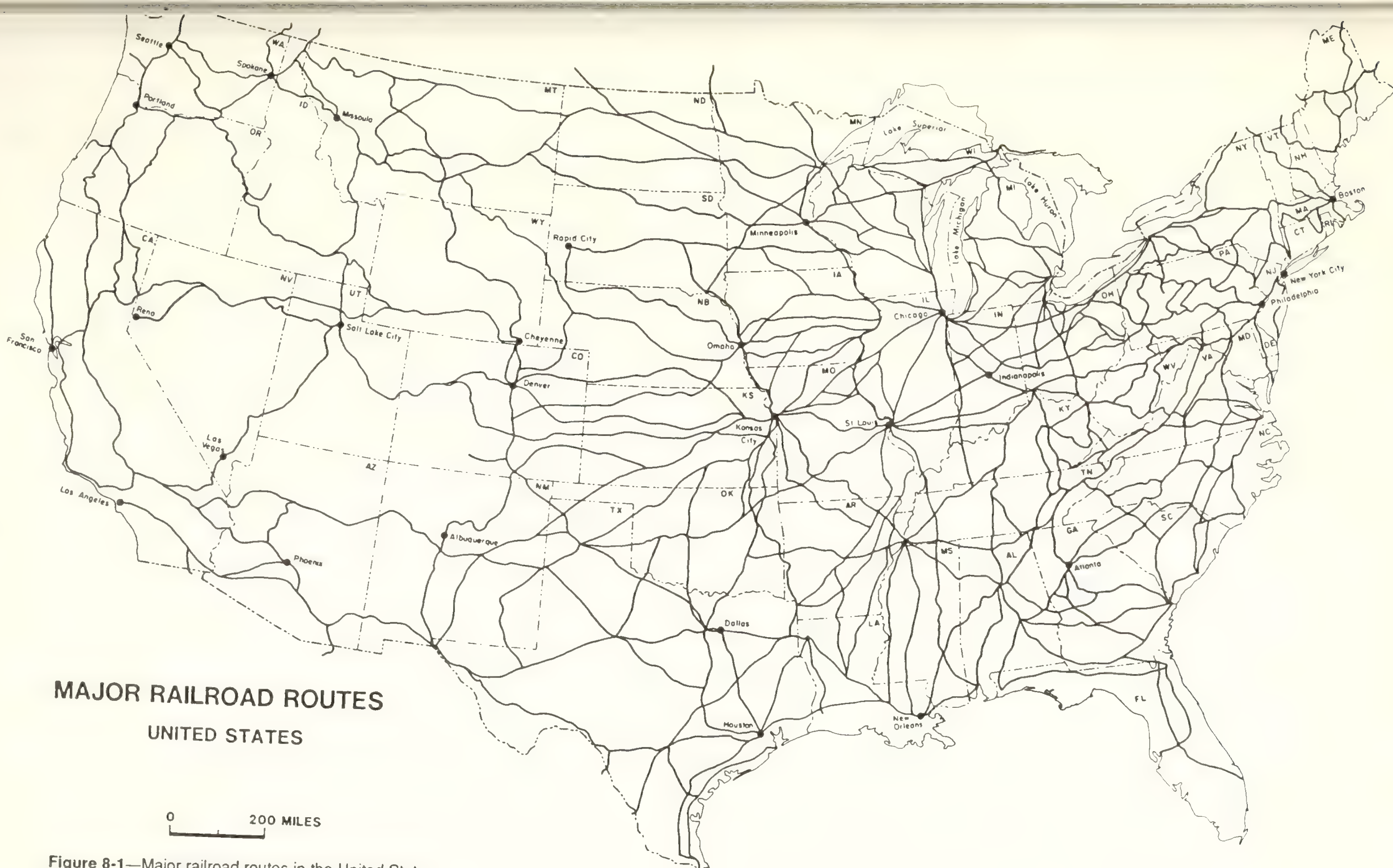

Figure 8-1—Major railroad routes in the United States.

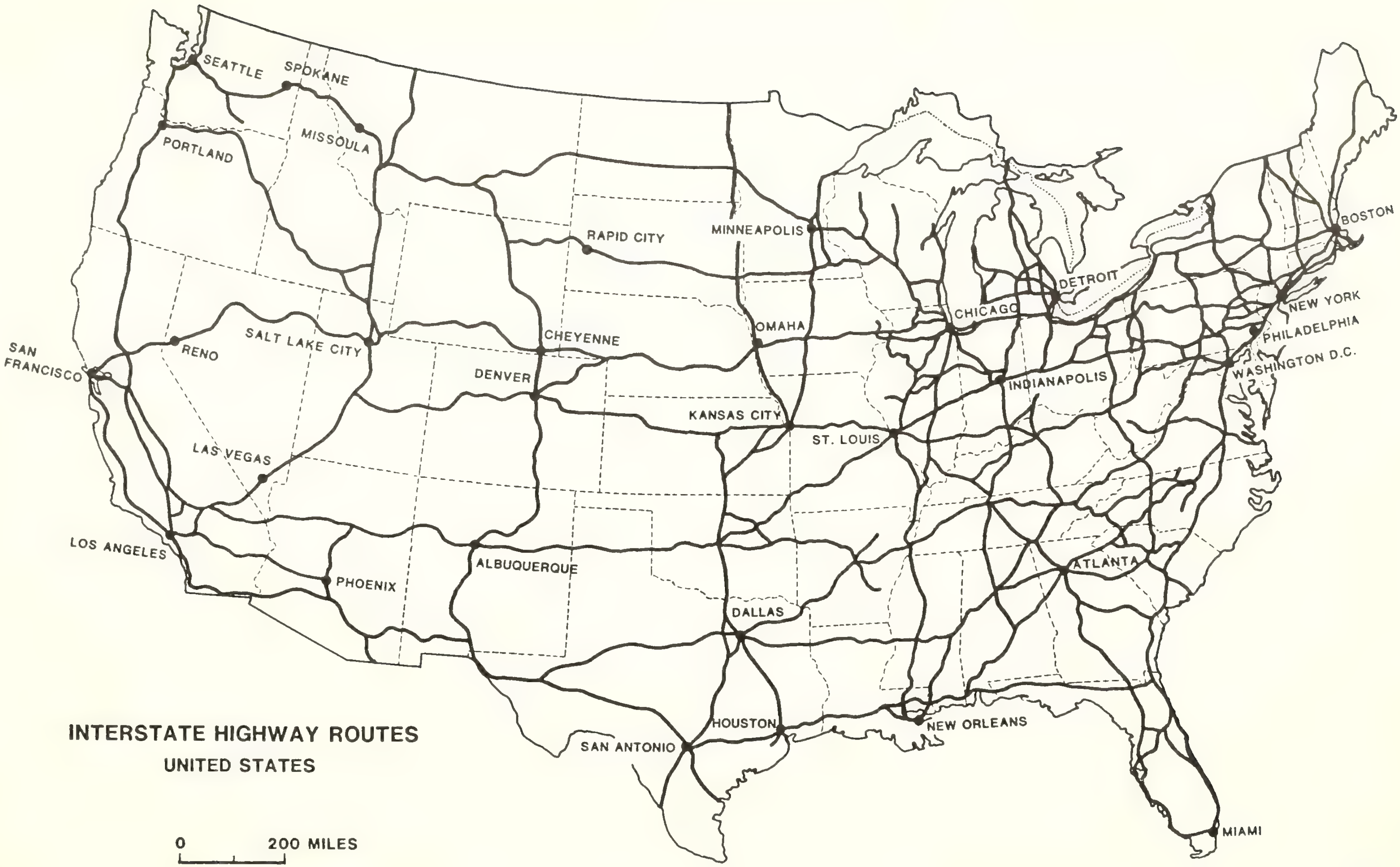

Figure 8-2—Interstate Highway System in the United States.

Table 8-1—Highway distances from Libby, MT, to 27 cities representing major markets in the United States, and estimated freight costs by truck and Burlington Northern boxcar (OSB, joists, edge-glued panels, and dowel products)

Region and city	Miles	Freight cost via truck[1]	Freight cost via rail boxcar: Published tariff	75 percent tariff[2]	Minimum weight
		Dollars per ton			Pounds
West					
Denver	1,081	54	31	23	110,000
Portland	509	25	32	24	90,000
Salt Lake	704	35	49	37	85,000
San Francisco	1,201	60	63	47	85,000
Seattle	439	22	25	19	100,000
Spokane	153	8			
Southwest					
Dallas	1,856	93	50	38	110,000
Las Vegas	1,113	56	59	44	85,000
Los Angeles	1,378	69	63	47	85,000
Phoenix	1,352	68	84	63	85,000
Reno	972	49	63	47	85,000
Midwest and East					
Boston	2,690	135	49	37	110,000
Chicago	1,727	86	49	37	110,000
Cleveland	2,057	103			
Kansas City	1,553	78	44	33	110,000
New York	2,524	126			
Omaha	1,352	68	37	28	110,000
Rapid City	848	42			
St. Louis	1,790	90	53	40	110,000
St. Paul	1,332	67	35	26	110,000
Washington DC	2,393	120			
South and Southeast					
Atlanta	2,327	116	114	86	95,000
Houston	2,089	104	95	71	95,000
Jacksonville	2,633	132	117	88	95,000
Memphis	1,999	100	95	71	95,000
Miami	2,982	149	131	98	95,000
New Orleans	2,330	117	97	73	95,000

[1]Based on $1.25 per loaded mile with a payload of 25 tons.
[2]Contract prices are typically significantly lower than published tariffs.

Rail shipping costs to the Seattle port will be about $19/ton, and to the Portland port about $24/ton (table 8-1).

Shipping in 40-foot containers seems practical for doweled products like tree props, and for edge-glued lumber panels. As discharged from the hot press, OSB and oriented-strand lumber will measure 8 feet wide and 32 feet long; such large panels could be loaded in 40-foot containers for remanufacture to desired dimension at destination—for example to metric dimension in Japan or China. Alternatively, sizing of panels and oriented-strand lumber could be accomplished at the Montana plant, and these smaller panels containerized for shipment to market. Because the fabricated joists are best transported to market in long lengths (64 feet) and cut to length at a distribution yard, containerized shipment may not be practical unless lengths are limited to less than 40 feet.

The primary target for containerized shipments could be OSB in large panel sizes (8 by 32 feet) for remanufacture in destination cities. A single 40- by 8- by 8-foot container could hold 200 such panels each weighing about 400 pounds, for a total cargo weight per container of 40 tons. A more likely weight, however, is 20 tons—which is the minimum container weight for economic rail transport, and which is light enough to be moved by truck from destination port to distribution yard. Maximum permissible container weight is generally 24 tons.

If Los Angeles, Osaka, or Shanghai could be developed into a major market, as many as 2,000 such 20-ton containers could be shipped annually. With this volume of shipment, rates per container (and per ton of OSB) from Portland—including loading and offloading charges—would be about as follows (the rail cost is estimated at $24/ton to Portland; the transport cost from destination port to distribution yard is estimated at $6/ton):

Destination	Ocean transport cost per 20-ton container, including loading and offloading	Ocean transport cost per ton	Land transport cost per ton	Total cost per ton
	Dollars			
Los Angeles	250	13	30	43
Osaka	1,100	55	30	85
Shanghai	2,350	118	30	148

Container service by ocean freight from Portland to Los Angeles was not available in December 1987, but should the service be started, the rate shown would be approximately correct. Loading and offloading costs per container in Shanghai are unavailable, but the tabulation includes $50 for this purpose.

8-4 SHIPPING WEIGHT OF PRODUCTS

Tree Props

Tree props turned green to 2 inches in diameter weigh about 0.61 pound per lineal foot (0.31 ton per thousand lineal feet) when dried to 10 percent moisture content, at which time they measure about 1.9 inches in diameter. This corresponds to a shipping weight of 31 lb/ft^3.

Studs

A thousand board feet (1,500 lineal feet or 54.69 ft^3) of studs dried to 10 percent moisture content and planed S4S should weigh about 1,727 pounds, or 0.86 ton.

Edge-Glued Panels

Edge-glued panels also weigh about 31 lb/ft^3, including adhesive, at a shipping moisture content of 8 percent of ovendry weight. This corresponds to a shipping weight of 1,938 pounds (0.97 ton) for 1,000 bd ft (500 ft^2) of 1.5-inch-thick panel.

Fabricated Joists

Including adhesive, fabricated joists shipped at 10 percent moisture content will weigh as follows:

Size	Per lineal foot	Per 1,000 lineal feet	Per 1,000 nominal board feet
	Pounds	*Tons*	*Ton*
2 by 10	2.9	1.45	0.87
2 by 12	3.1	1.55	.78
2 by 14	3.3	1.65	.71
2 by 16	3.5	1.75	.66

Oriented-Strand Board

Oriented-strand board, including adhesive and wax content, shipped at 8 percent moisture content, will weigh about 44.2 lb/ft^3. This corresponds to 1,381 pounds (0.69 ton) per M ft^2 of $^3/_8$-inch-thick panels and 1,611 pounds (0.81 ton) per M ft^2 of $^7/_{16}$-inch-thick panels.

Oriented-strand lumber 1.5-inch thick, including adhesive and wax, shipped at 8 percent moisture content, will weigh about 40 lb/ft^3. This corresponds to the following shipping weight per M bd ft of product ripped to standard lumber widths:

Nominal lumber size	Weight/M bd ft	
Inches	*Pounds*	*Tons*
2 by 4	2,188	1.09
2 by 6	2,292	1.15
2 by 8	2,250	1.13
2 by 10	2,312	1.16
2 by 12	2,344	1.17

CHAPTER 9: MARKETS, PRODUCT SELLING PRICES, AND DISTRIBUTION METHODS

CONTENTS

9-1 GEOGRAPHIC AND DEMOGRAPHIC CONSIDERATIONS

Foreign and Domestic Timber Supplies

A report of this scope cannot deal exhaustively with the timber supply-demand system of the world, but some general comments are appropriate. It is well accepted that the large-timber resources of the world are being rapidly harvested; much of this large-tree resource is being replaced by trees that will be of fairly small diameter when harvested. In the United States, the old-growth Douglas-fir, hemlock, Sitka spruce, sugar pine, western white pine, ponderosa pine, and western redcedar of the West are being depleted and replaced by second-growth timber that will likely have average diameter at breast height (d.b.h.) of 16 inches or less when harvested. The large old-growth southern pine trees of the South—and the eastern white pine trees of the North Central and Northeastern States—have been, for the most part, liquidated and replaced by second-growth trees that will average perhaps 12 inches in d.b.h.

Current harvesting and management practices in Canadian forests will similarly yield small-diameter trees in the Canadian forests of the future.

The coniferous forests of Europe are largely in stands managed to yield trees of moderate size—averaging perhaps 13 inches or less in diameter when harvested.

While the coniferous forests of Russia are vast, much of the resource—particularly in Siberia—is remote and is considered by many to be uneconomic to harvest and sell in world markets in the next two or three decades. For this reason, Russian timber sales will likely not be a strong depressant on world prices for logs during the life of the plant under consideration in this report.

For two reasons the large hardwood logs from Southeast Asia and the South Pacific regions are becoming largely unavailable to consuming industries in the rest of the world. First, the supply of such large logs is being depleted, and second, the countries of origin are increasingly legislating against export of logs—instead favoring internal manufacture of wood products for export.

The exotic pines—principally *Pinus radiata* and the southern pines—in the extensive coniferous plantations of the southern hemisphere (for example, in New Zealand, Chile, Australia, and Brazil) are largely managed on short rotations yielding relatively small-diameter trees.

In summary, it seems likely that commercial world forests of the future will not be predominantly comprised of large-diameter trees, but instead will hold trees generally 10 to 16 inches in d.b.h. when harvested. This suggests that the long wide structural lumber, and the wide thick clear lumber characteristically yielded by old-growth trees will be less readily available in world trade—and will be replaced in large degree by fabricated or reconstituted wood products such as the fabricated joists (figs. 3-2 and 3-3), edge-glued panels (fig. 3-5), and OSB (fig. 3-6) discussed in chapter 3.

The foregoing comments are not intended to imply that the overall harvest of timber will diminish in the next several decades, but simply that average log diameter will diminish.

Export vs. Domestic Markets for Manufactured Wood Products

The market for coniferous logs exported from western North America to Pacific Rim countries—principally to Japan, but also to Korea, Taiwan, and China—developed strongly in the last 15 to 20 years, and was particularly robust during mid-1987. These logs are transported in bulk-loaded ships typically with five holds each accommodating two 40-foot log lengths and totaling perhaps 1,160,000 ft^3, and carrying 25,000 tons. Ships of this capacity might be chartered in 1987 for about $450,000 to carry logs from the West Coast of North America to Japan, Korea, or the People's Republic of China; such a charter would typically require 1 day for loading, 14 days in transit, and 1 to 3 days to offload. Longer charters—for example to Turkey (requiring 1 day to load, 23 days in transit, and 1 day to offload)—might cost $760,000.

Log diameters specified by customers in these countries are generally greater than diameters available from the lodgepole pine forests of the Rocky Mountain Region, although there might be a modest market for small utility poles (40 feet long with 4-inch minimum top diameter and at least a 7-inch butt).

Export volumes to Pacific Rim markets of West Coast coniferous logs exceed lumber exports of these species by 4:1 or 5:1. Few timber merchants in the export business believe that products manufactured from small inland species (such as lodgepole pine) can find a major place in the export trade. These merchants believe that only very high-value products (for example those with a domestic value of near $1,000/M bd ft) can originate in the Rocky Mountain Region and can be sold in the export market. Such products would be shipped in 20- or 40-foot-long containers, with rates per container such that shipping cost per ton of product might be $85 to Japan and $148 to China ports (see section 8-3). In China, only certain ports are equipped to receive containers; such ports would include Xingang (near Beijing), Shanghai, Canton, and Dalian (near Tianjan and Beijing).

It is difficult to find markets for even these high-value products because virtually all of the Pacific Rim potential customers desire to convert logs to products, rather than import the products. Niche markets are present, however; for example, log cabin manufacturers in the Bitterroot Valley of Montana have been successful in obtaining significant orders from merchants in Japan.

In summary of these comments on the potential for export versus domestic markets, knowledgeable timber merchants are nearly unanimous in believing that the United States should receive primary emphasis in any strategy to market products produced from lodgepole pine in the Rocky Mountain Region.

Population Distribution in the United States Related to Freight Rates

Study of freight rates (table 8-1) suggests that commodities priced to be competitive with a freight rate of $30/ton or less will be limited to a market radius including Denver, Portland, Seattle, Salt Lake (via the Union Pacific), Omaha, and St. Paul-Minneapolis. If the market price can absorb a $31 to $37 per ton rail freight rate, the major markets of Kansas City, Chicago, and Boston can be accessed. Only by paying rail freight charges of $38 to $47 per ton can markets in Dallas, St. Louis, San Francisco, Los Angeles, Reno, and Las Vegas be reached.

It is obvious from study of population distribution in the United States (fig. 9-1) that the market reachable with a $30 freight rate is very small compared to that encompassed by a $37 or $48 ceiling on rail rates.

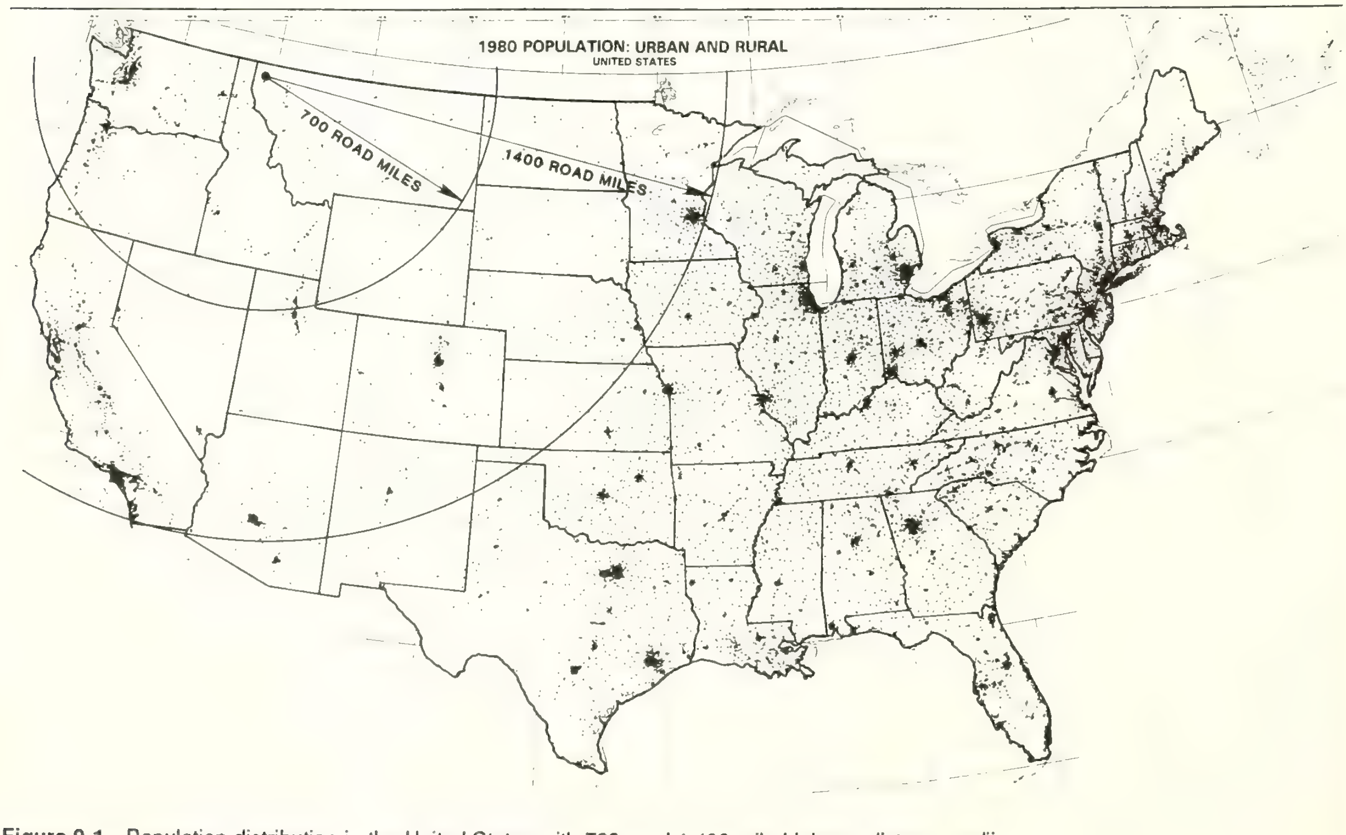

Figure 9-1—Population distribution in the United States with 700- and 1,400-mile highway-distance radii (approximate) from the Libby-Troy area indicated.

Table 9-1—Summary of annual product volumes, prices, and annual sales

Product	Annual output	Price per unit	Net annual sales
		Dollars	
2-inch tree props	2 million pieces averaging 9 feet long	0.095/ lineal foot	1,710,000
2-$^5/_8$-inch tree props and rails	520,000 pieces averaging 14 feet long	0.15/ lineal foot	1,092,000
10-inch-deep fabricated joists	6,850,000 lineal feet	0.66/ lineal foot	4,521,000
12-inch-deep fabricated joists	13,700,000 lineal feet	0.72/ lineal foot	9,864,000
Edge-glued panels	6,500,000 ft^2 (1.5-inch-thick basis)	750/M ft^2	4,875,000
2 by 4 studs	4 million bd ft	181/M bd ft	724,000
Market OSB	117,500,000 ft^2 of $^7/_{16}$-inch sheathing	130/M ft^2	15,275,000
Pulp chips	6,500 tons, ovendry basis	18.33/ ovendry ton	119,000
Particleboard furnish	14,379 tons, ovendry basis	1.00/ton	14,000
			38,194,000

For some products, notably tree props, the major market (southern California) is accustomed to delivery by truck with freight rates as high as $69 per ton (to Los Angeles). Unfortunately, the two counties in the United States with the greatest population increases since 1980 are expensive to reach by rail; the rate to Los Angeles County in California is $47 per ton and the rate to Maricopa County in Arizona (Phoenix environs) is $63 (table 8-1).

With the foregoing information and summary price and production data (table 9-1) in mind, discussions of markets, product selling prices, and distribution methods for the various products follow.

9-2 TREE PROPS

Markets

The market for lodgepole pine tree props (fig. 3-1) was expanded greatly by North Idaho Post and Pole and associated marketing companies selling to large landscape supply houses in California. This company, with production facilities in Hayden Lake, ID, is probably the major seller of lodgepole pine tree props and related pole products for agriculture. Lodgepole pine, because of its good stem form, small knots, and high strength-to-weight ratio, is the major species utilized for tree props. While many tree props are sold untreated, most are probably treated with preservative—sometimes at the originating plant and sometimes in transit near the point of use.

Other major producers of lodgepole pine doweled tree props, all with manufacturing plants in Montana, include Bouma Post Yards, Lincoln (with facilities to pressure-treat products with chromated copper arsenate); Desert Mountain Forest Products, Glacier; Flathead Post and Pole Yard, Dixon (with soak tanks to impregnate products with pentachlorophenol in oil); and Grizzly Timber Products and Nine Mile Posts and Rails, both near Missoula.

In aggregate these Idaho and Montana producers have 10 or 12 doweling machines in operation producing tree props—usually on a one-shift-per-day basis, but sometimes operating two or even three shifts.

As noted previously, the major market for tree props is in California, with smaller sales in other southwest markets such as Reno, Las Vegas, and Phoenix. Little effort has been made to develop markets in the Midwest. If markets in the Deep South are to be developed, it is probable that the props would have to be incised to insure preservative retention adequate to withstand the decay and termite hazard present in this market area.

Conversations with producers suggest that the market, while finite, is not yet fully developed. In the plant under consideration in this analysis, only one doweling machine is contemplated—but it would be scheduled for three-shift operation, probably 7 days a week. With vigorous sales efforts and competitive pricing, it seems reasonable that the market will easily absorb the output proposed.

Product Selling Prices

Wholesale prices for untreated 2-inch diameter tree props have declined somewhat during the last several years from about $0.125 per lineal foot to about $0.10 per lineal foot f.o.b. Montana or Idaho plants. In the plant under study, a net price of $0.095 per lineal foot (after all discounts and commissions) f.o.b. plant is proposed. Costs of treating with chromated copper arsenate would be done in transit at extra cost.

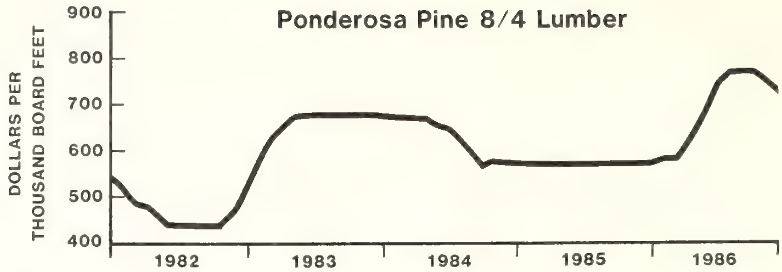

Figure 9-2—Five-year price trend for ponderosa pine kiln-dry 8/4 #2 shop lumber, net f.o.b. mill. Data from Random Lengths (Richards 1987).

Some props $2^5/8$ inches in diameter would also be produced in conjunction with manufacture of flanges for fabricated joists. The net f.o.b. mill price proposed for these larger props and rails is $0.15 per lineal foot.

Distribution Methods

Lodgepole pine tree props have gained such acceptance in certain markets that one of the several major distributors of wood products should find it profitable to sell the entire output of the proposed plant. Strength of props from northern Montana should be superior to those from sources in more southerly latitudes (see section 4-1), so it should be possible to maintain product superiority over potential competitors to the south.

Lacking such a sales agreement, it seems likely that one inhouse salesperson could market the plant output of tree props.

9-3 EDGE-GLUED PANELS

Markets

The edge-glued panels proposed (fig. 3-5) will contain the small knots characteristic of lodgepole pine. Although the stem sections for conversion to edge-glued panels will have been visually graded and selected for sound red knots, it seems likely that two grades of panels will result—a sound red-knot grade, and a sound black-knot grade. Also, the panels will be made available with either a colorless glue line for interior applications, or with a dark glue line for exterior uses.

Millwork manufacturers in the United States are accustomed to using clear cuttings made from shop grades of ponderosa, western white, and sugar pines—but thick planks of shop grades of these pines will inevitably become scarcer and more expensive with the passing of years and liquidation of the very large trees which yield such wood. For this reason, it is likely that more economical wood containing small knots will become acceptable for many millwork uses. If such wood is available in specified thicknesses, widths, and lengths, economies in raw material utilization and manufacturing procedures should be achievable.

Manufacturers in Finland, West Germany, and Japan have installed plants to produce panels similar to that illustrated in figure 3-5. In these countries uses for the panels include the following:

bed headboards	plinths
bedrails	school desk lids
benches	shelves
cabinet doors	shutters
chair seats	stair rails
chairs	stair treads
door frames	table tops
doors	truck flooring
garage door rails	turnings
garage door stiles	wall panels
garden furniture	window frames
load-bearing wood	windowsills
lockers	wooden toys
office desks	work tops
playground furniture	

Because annual product output (table 9-1) is only on the scale of a very small sawmill, the proposed operation would need to capture only a miniscule share of the market in the United States for knotty grades of the products in the foregoing list.

It is contemplated that most sales will be of rectangular blanks of specified length, width, and thickness; the industrial user will then fabricate these blanks (by moulding, turning, shaping, and perhaps veneering) into the products of choice. Moisture content at shipment will be about 8 percent of ovendry weight. By the nature of log selection and panel assembly (fig. 3-5), the growth rings will be closely spaced—averaging less than one-sixteenth inch in width—and oriented so that width and thickness shrinkage will be intermediate between values for pure radial and tangential shrinkage; that is, the extreme width shrinkage characteristic of wide flat-sawn lumber will be avoided in the proposed edge-glued panels.

Product Selling Prices

Because sound-knotted edge-glued panels of the type contemplated are not now a commonly accepted commodity in commerce, the price obtainable is difficult to estimate. As suggested in earlier paragraphs, shop-grade

lumber brings a high price and, because of decreasing availability of large-diameter trees, can be expected to increase in price in the future. For the years 1982 through 1986, the price for kiln-dry ponderosa pine 8/4 #2 shop lumber averaged $591/M bd ft net f.o.b. mill (fig. 9-2). Shop lumber in 8/4 thickness has a surfaced thickness of $1^{13}/16$ inches; this price amounts to $1,182/M ft² of such lumber. If this ponderosa pine lumber were produced at a net thickness of 1.5 inches and equivalently priced, the price per square foot should be $978/M ft². But, of course, shop ponderosa pine—a cutting grade—is not directly comparable to the sound-knotted panels proposed that are intended for use in their entirety.

Blanks for garage door rails and stiles that permit inclusion of sound knots are perhaps a better indicator of prices obtainable for blanks cut from the proposed sound-knotted lodgepole pine panels. Industry is currently offering about $1.80 for a sound-knotted blank 9 feet long, 1.375 inches thick (scaled as 6/4), and 3.375 inches wide (scaled as 3.5 inches to include kerf). This price per piece is equivalent, based on cubic content including kerf to rip, to about $750/M ft² of 1.5-inch-thick panel.

Another clue to the price obtainable is the wholesale price of 1.5-inch-thick laminated truck flooring, which brings about $1,800 per thousand lineal feet of pieces 16 inches wide, or $1,350/M ft². Truck flooring is a sound-knotted product, but because it is mainly made in long lengths with finger-jointed components of Douglas-fir and larch, it is not exactly comparable to the proposed product.

From study of the price data available, it seems conservative to use in this feasibility analysis a price of $750/M ft² for panels sanded to 1.5 inch thickness. Obviously, price per square foot will vary with thickness and panel grade, but the price noted is considered an average attainable price net f.o.b. mill.

Distribution Methods

It is evident from the previously listed products that could potentially utilize the edge-glued panels that sales efforts must be concentrated on the industrial sector, rather than on retail lumber yards. Close direct communication between seller and buyer is needed to serve such industrial markets. It is proposed, therefore, that half the sales of the edge-glued panels—and blanks cut from them—be handled by an inhouse salesperson and the balance through wholesalers. Because of the high value of the edge-glued panels, it is likely that freight costs will not be an insurmountable barrier to Midwestern and Southwestern markets.

In addition to the industrial panels, some significant volumes of shrink-wrapped shelving products could likely be sold to the "shoulder trade" through retail lumber yards.

9-4 STUDS

Markets

Two-by-four 8-foot studs are one of the major wood commodities sold in the United States. Well-manufactured kiln-dry lodgepole pine studs find a ready market if competitively priced. Because the production volume contemplated (table 9-1) is miniscule in relation to the size of the market, the studs should be salable within the market area encompassed by a $30/ton rail freight rate, that is, including Denver, Salt Lake, Portland, Seattle, Omaha, and St. Paul-Minneapolis.

Product Selling Prices

Fluctuations in stud prices have been considerable (fig. 9-3). For the 5 years 1982 through 1986, kiln-dry spruce and lodgepole studs have averaged $181/M ft² net f.o.b. mill. This average price has been used in this feasibility analysis.

Distribution Methods

Distribution through a wholesaler is probably the most economical way of marketing the studs.

9-5 FABRICATED JOISTS

Markets

In the United States, annual western (including Rocky Mountain) production of #2 and better lumber of all coniferous species totals about 1.674 billion bd ft of 2 by 10's and 1.097 billion bd ft of 2 by 12's. Annual production of southern pine 2 by 10's and 2 by 12's is about 0.650 billion bd ft. It is difficult to say what proportion of this output is utilized for floor and ceiling joists, but perhaps half the output goes to these uses.

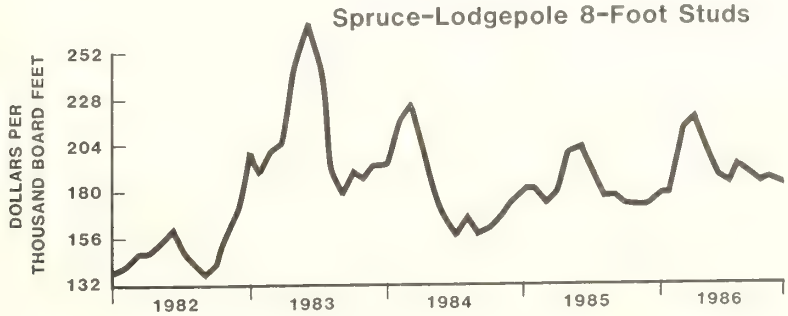

Figure 9-3—Five-year price trend for spruce-lodgepole kiln-dry 2 by 4 studs 8 feet long. Data from Random Lengths (Richards 1987).

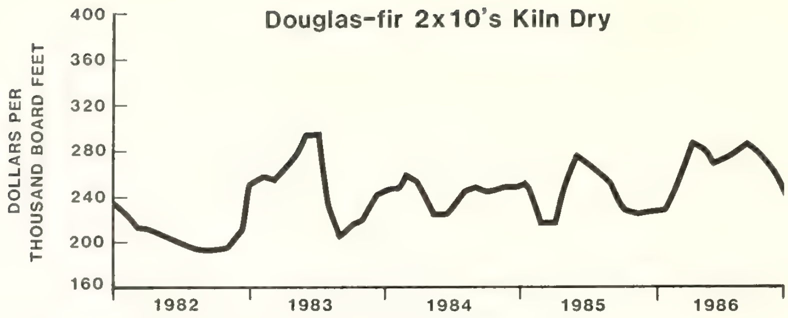

Figure 9-4—Five-year price trend for kiln-dry Douglas-fir #2 and better random-length 2 by 10 lumber, net f.o.b. mill. Data from Random Lengths (Richards 1987).

The proposed production of fabricated joists (table 9-1), while only about 1 percent of the lineal footage of structural 2 by 10's and 2 by 12's produced in the United States, is still a significant volume to market.

The proposed joists, because they are significantly lighter, drier, stiffer, stronger, and more uniform in mechanical properties than sawn lumber joists, should—over time—gain enthusiastic acceptance by builders. One of their most compelling advantages is quick availability from distributing yards in schedules of precise, but nonstandard, lengths specified by the builder. Additionally, the joists will be made under strict quality control and shipped at a uniform low moisture content of about 8 percent of ovendry weight. Close control of moisture content not only results in a lighter product compared to sawn lumber, but minimizes shrinkage in depth and thickness. In contrast, excessive shrinkage in incompletely dried sawn joists can cause significant problems for builders and building occupants.

In the past, sales of competitive fabricated joists for residential and light commercial construction were heavily concentrated in 10- and 12-inch depths, but recently 14- and 16-inch joists are in demand. Conversations with major distributors of fabricated joists suggest that consumption of lineal footage by depth is about as follows:

Nominal joist depth	Percentage of lineal feet sold
Inches	
10	15
12	51
14	22
16	12
	100

Although most of the discussion in this analysis has been focused on 10- and 12-inch joists, it is evident that the plant must also produce joists 14 and 16 inches in depth.

As this analysis has proceeded, funding has not proved sufficient to conduct the product and market analyses that would assure success in marketing the joist output of the proposed plant. Because commercial acceptance of the joists is so critical to the financial success of the plant, and hence the utilization and reforestation of the public forest stands at issue (see section 1-4), we believe USDA funding for market analysis is merited. To date such funding has not been allocated, however.

Product Selling Prices

The price of kiln-dry Douglas-fir 2-by-10, #2 and better, random-length lumber has fluctuated significantly in recent years but during the 5-year period 1982 through 1986 has averaged $259/M bd ft net f.o.b. mill (fig. 9-4), or $0.43 per lineal foot.

The price of fabricated joists has been very stable at a considerably higher price per lineal foot. The major manufacturer of fabricated joists prices 9.5-inch-deep joists at about $0.735 per lineal foot and 11.875-inch-deep joists at about $0.804 per lineal foot, net f.o.b. western mill after all discounts and commissions.

For the purposes of this analysis, joists produced by the proposed plant are priced 10 percent lower, that is, $0.66 per lineal foot for joists 10 inches deep, and $0.72 for joists 12 inches deep; both prices are net f.o.b. mill after all discounts and commissions. To simplify computations, it has been assumed that only 10- and 12-inch joists would be sold, and that their sales ratio would be 1 lineal foot of 10-inch for each 2 lineal feet of 12-inch (table 9-1).

Distribution Methods

Of the various products from the proposed plant (table 9-1), the fabricated joists present the most difficult marketing problem. A sawmill in the Rocky Mountain Region manufacturing perhaps 40 million bd ft annually of a known product such as kiln-dry #2 and better random-length Douglas-fir and larch 2 by 10's and 2 by 12's, could expect to market such lumber through established wholesale networks. A new product such as the fabricated joists (figs. 3-2 and 3-3), however, presents a significant marketing challenge.

To put the challenge in perspective, the annual output of fabricated joists shown in table 9-1 represents a shipping weight of about 28,085 tons, or about 432 65-ton carloads. The very largest distributors of competitive fabricated joists—all in the Northeast—each market about 50 carloads annually, and it has taken such distributing yards several years to attain this volume. This suggests that a network of at least 50, and perhaps as many as 200, distributing yards would be required to market the plant output.

Some yards would stock the joists in relatively short lengths—for example 16 to 24 feet. To make most effective use of the product, however, the joists should be shipped to the distributor in the maximum length practical for the proposed manufacturing plant, that is 64 feet. Two experienced operators working in unison on a pair of large forklifts require about 3 hours to unload a 65-ton unitized load of such long fabricated joists from a flatcar. A 64-foot length of the proposed 12-inch-deep joist will weigh about 198 pounds. The joists would be stored near trim saws and cut to length as specified by builders. Joists would mostly be trimmed to 28 feet or less. Short trim ends would be converted to blocking.

Supplying the joists through distribution yards would assure ready and prompt availability to builders. Rail cars may have to be ordered 6 to 8 weeks in advance of shipment and may be in transit an average of 14 days to the East Coast. Three technical sales representatives each making two calls per day could visit about 100 distributors three times annually. Sales and technical assistance calls probably should not fall below this frequency.

A large investment in time, energy, and money by the sales staff would be required in the 2 years before plant startup to get the distribution system in place so that the plant could come up to full production within the first 3 months of operation.

Because the joists will be produced under strict quality control and are designed to be significantly stiffer and stronger than major competitive joists (table 3-3)—although slightly heavier—and will be priced 10 percent below the price of the competitive joists, it would seem that joists produced by the proposed plant can be competitive.

9-6 ORIENTED-STRAND BOARD

Markets

The annual consumption of structural panels is increasing in both the United States and Canada, and is expected to further increase to the end of the century (figs. 9-5 and 9-6). In the United States, structural plywood consumption is forecast to increase moderately through 1990, but thereafter decrease (fig. 9-5). In Canada, however, structural plywood consumption is decreasing and will likely continue to decrease (fig. 9-6). In both countries the consumption of waferboard/OSB structural panels is forecast to increase through the year 2000. Study of the consumption of all of the major panel products in North America reveals an almost explosive growth in demand for waferboard/OSB (fig. 9-7). From 1996 through 2000, annual consumption of waferboard/OSB is forecast to be about 15 billion ft^2, $^3/_8$-inch basis (fig. 9-5).

As noted previously, this trend is driven by higher timber prices and increasing price but diminishing quality of solid-wood products. Countervailing these influences, however, is the increasing price of phenol formaldehyde resins. For example, the cost of resin in a thousand square feet of $^7/_{16}$-inch OSB rose from about \$15 in 1986 to about \$17 by the end of 1987.

In 1984, installed plant annual capacity for OSB/waferboard in the United States was about 3.4 billion ft^2, $^3/_8$-inch basis (table 9-2). Additionally, Canadian capacity totaled about 1.6 billion ft^2 (table 9-3). (An updating by the Forest Products Laboratory, Madison, WI, the end of 1987; suggests that current capacity is near double that tabulated for 1984.)

Readers interested in a brief account of the inception of the structural flakeboard industry (waferboard and OSB) are referred to Koch and Springate (1983).

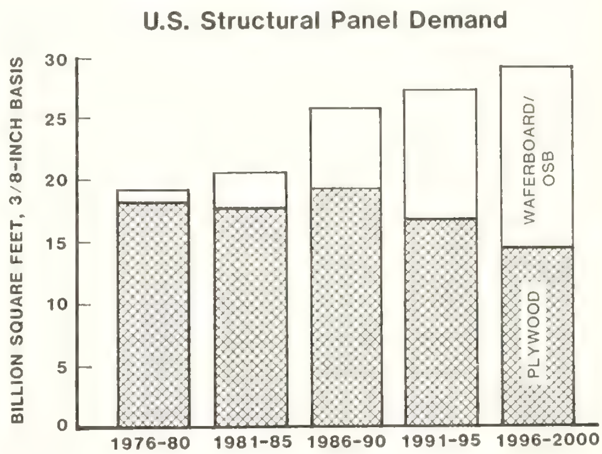

Figure 9-5—Annual demand for OSB/waferboard and plywood structural panels in the United States since 1976, with projections to the year 2000. Data from Bernard E. Fuller, Resource Information Systems, Bedford, MA (March 25, 1987).

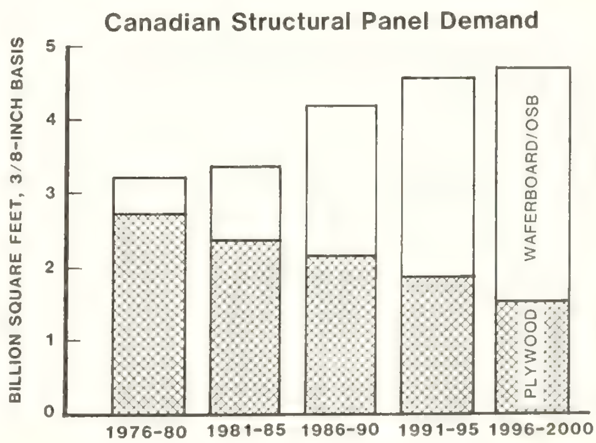

Figure 9-6—Annual demand for OSB/waferboard and plywood structural panels in Canada since 1976, with projections to the year 2000. Data from Bernard E. Fuller, Resource Information Systems, Bedford, MA (March 25, 1987).

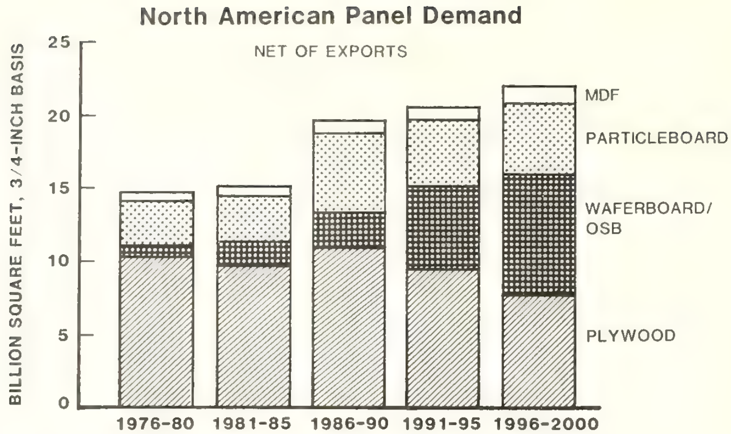

Figure 9-7—North American annual demand for panels of medium-density fiberboard (MDF), particleboard, OSB/ waferboard, and plywood since 1976, with projections to the year 2000. Data from Bernard E. Fuller, Resource Information Systems, Bedford, MA (March 25,1987).

Table 9-2—Data on plants producing waferboard (W) and oriented strand board (OSB) in the United States (from information compiled in 1988 by R. Geimer, Forest Products Laboratory, USDA Forest Service)

Company	Species	Wood used per year	Annual volume of plant	Press size	Press openings	Date of startup	Product
		Cords	*Million ft^3 $^3/_8$-inch*	*Feet*	*No.*	*Year*	
Arrowood Technologies Roxboro, NC	Yellow poplar	[1]—	130	—	—	1987	Comply structural lumber (veneer over OSB)
Blandin Wood Products Grand Rapids, MI	Aspen	200,000	285	8x28	12	1972	W; 4-layer $^1/_4$-$^3/_4$; sheathing; T&G[2]; cut stock
Georgia Pacific Corp. Woodland, ME	35% spruce 35% fir 30% mixed softwoods	120,000	170	8x16	16	1980	W; 4-layer $^1/_4$-$^3/_4$; decorative panels; sheathing; T&G
Georgia Pacific Corp. Dudley, NC	Southern pine	—	220	—	—	1987	OSB
Georgia Pacific Corp. Emporia, VA	—	—	—	—	—	Planned	OSB
Georgia Pacific Corp. Glade Spring, VA	—	—	200	—	—	Planned	OSB
Georgia Pacific Corp. Grenada, MS	—	—	250	—	—	1987	OSB
International Paper Co. Nacogdoches, TX	—	—	200	—	—	1987	OSB
J.M. Huber Corp. Easton, ME	Aspen	112,000	160	8x16	12	1983	OSB; 3-layer $^1/_4$-$^3/_4$; sheathing; T&G
Louisiana-Pacific Corp. Corrigan, TX	Southern pine	—	150	4x25	14	1983	OSB; 3-layer $^1/_4$-$^5/_8$; 3-layer sheathing; flooring
Louisiana-Pacific Corp. Hayward, WI	Aspen	274,000	350	8x16 8x16	12 12	1979 1982	OSB; 3-layer $^1/_4$-$^3/_4$; sheathing; embossed lap siding and modular panels

(con.)

Table 9-2 (Con.)

Company	Species	Wood used per year	Annual volume of plant	Press size	Press openings	Date of startup	Product
		Cords	Million ft³ 3/8-inch	Feet	No.	Year	
Louisiana-Pacific Corp. Houlton, ME	Aspen	137,000	175	8x16	12	1981	OSB; 3-layer 1/4-3/4
Louisiana-Pacific Corp. Kremmling, CO	Aspen & lodgepole pine	60,000	100	8x16	8	1984	OSB; 3-layer 1/4-3/4, sheathing
Louisiana-Pacific Corp. Montrose, CO	Aspen	60,000	125	8x16	8	1984	OSB; 3-layer 1/4-3/4; sheathing; T&G
Louisiana-Pacific Corp. Athol, ID	Lodgepole pine	75,000	90+	8x16	8	1984	OSB; 3-layer 1/4-3/4; sheathing
Louisiana-Pacific Corp. Logansport, LA	—	—	—	—	—	Planned	OSB
Louisiana-Pacific Corp. Grenada, MS	—	—	75			Planned	OSB
Louisiana-Pacific Corp. Urania, LA	—	—	150	—	—	1987	OSB
Louisiana-Pacific Corp. Dungannon, VA	Yellow poplar	—	100	—	—	1986	OSB
Louisiana-Pacific Corp. Two Harbors, ME	Aspen	—	100	8x16	8	1985	OSB; 3-layer, sheathing; paper-overlay siding
Louisiana-Pacific Corp. Jackson Co., GA	—	—	250	—	—	—	OSB
Louisiana-Pacific Corp. Sagola, MI	—	—	260	—	—	—	OSB
Louisiana-Pacific Corp. New Waverly, TX	—	—	100	—	—	—	OSB
Martco Lemoyen, LA	60 percent sweetgum and oak; 40 percent other hardwoods	84,000	170	8x16	16	1983	OSB; 3-layer 1/4-3/4; sheathing
Northwood Bemidji, MN	Aspen	200,000	240	8x24	14	1981	OSB; 4-layer 1/4-3/4; T&G; grooved wall panels
Potlatch Corp. Bemidji, MN	Aspen	—	180 to 450	4x24	22	1981 1985	OSB; 5-layer; sheathing
Potlatch Corp. Cook, MN	Aspen	150,000	170	4x24	22	1983	OSB; 5-layer 3/8-3/4; sheathing; flooring
Temple-Eastex, Inc. Claremont, NH	White pine and aspen	65,000	110	4x16	16	1981	OSB; 3-layer 7/16-3/4, sheathing; flooring
Weyerhaeuser Co. Grayling, MI	Aspen plus some jack pine and mixed hardwoods	290,000	300	8x24	16	1982	OSB; 3-layer 1/4-3/4; sheathing; flooring
Weyerhaeuser Co. Elkin, NC	—	—	200	—	—	1987	OSB

[1]—means missing data.
[2]Tongue and groove panels.

Table 9-3—Data on plants producing oriented strand board or waferboard in Canada (from information compiled in 1988 by R. Geimer, Forest Products Laboratory, USDA Forest Service)

Company	Annual volume of plant	Press size	Press openings	Date of startup
	Million ft³ 3/8-inch	*Feet*	*No.*	*Year*
Forex Val d'Or, PQ	140	8x16	12	1982
Grant Lumber Englehart, ON	160	8x16	14	1981
Great Lakes Thunder Bay, ON	110	8x20	10	1976
Louisiana-Pacific Corp. Dawson Creek, BC	240	8x24	12	1988
Malette Timmons, ON	60	8x16	6	1973
Malette St. Georges, PQ	130	8x16	12	1981
MacMillan Bloedel Thunder Bay, ON	135	4x24	16	[1]—
MacMillan Bloedel Hudson Bay, SK	180	4x16 4x16	14 18	1969
Normick Perron La Sarre, PQ	60	8x16	6	1980
Northwood Chatham, NB	160	8x24	11	1979
Pelican Mills Drayton Valley, AB	240	8x24	12	1987
Pelican Mills Edson, AB	240	8x24	12	1983
Weldwood Longlac, ON	135	4x16	24	1974
Weldwood Slave Lake, AB	135	4x16	24	-

[1]—means missing data.

Product Selling Prices

The principal OSB commodity produced by the proposed plant will be 7/16-inch-thick sheathing panels. Price history on this product is limited to recent years because it is a new commodity. For the 5-year period 1982 through 1986, the price of 7/16-inch-thick sheathing averaged about $155/M ft² delivered Chicago (1982 and 1983), or net f.o.b. North Central mill (fig. 9-8). During 1984, 1985, and 1986, tongued-and-grooved panels 3/4-inch thick for decking averaged $280/M ft² net f.o.b. North Central mill (fig. 9-9), offering a slightly higher revenue per ton of product compared to 7/16-inch sheathing, but requiring one additional operation to manufacture.

With significant new manufacturing capacity coming onstream each recent year, prices for OSB have not been buoyant, but neither have they been consistently depressed (fig. 9-8)—although in November (typically a month of low demand) 1987, the price of 7/16-inch sheathing was at a low of $131/M ft² f.o.b. North Central mill. North Central mills have significantly less freight cost to reach important Midwest and Eastern markets than the proposed mill in northwestern Montana.

For the purposes of this analysis, 7/16-inch OSB sheathing is priced at $130/M ft², net f.o.b. mill after all discounts and commissions.

Distribution Methods

It is contemplated that 80 to 90 percent of the plant output of OSB will be marketed through a long-term (5 to 7 years) sales agreement with a major producer and distributor of forest products—one with a network of distribution warehouses. Such agreements typically guarantee sales of the commodity as it is produced—at market price.

The balance of the output will be sold by inhouse salespersons.

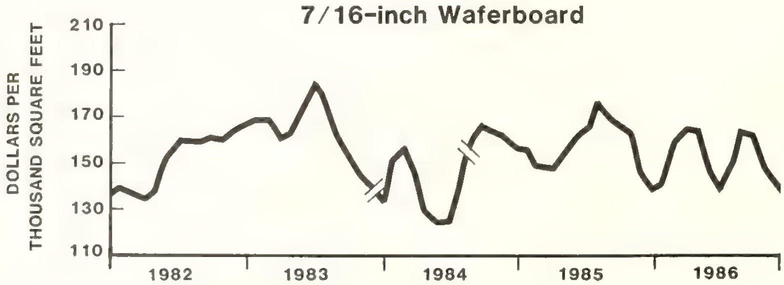

Figure 9-8—Five-year price trend for 7/16-inch-thick waferboard (including OSB). Prices prior to 1984 delivered Chicago; prices thereafter are net f.o.b. North Central mill. Data from Random Lengths (Richards 1987).

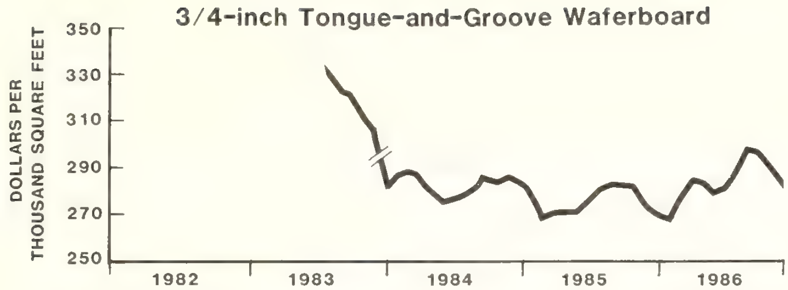

Figure 9-9—Price trend for 3.5 years for 3/4-inch tongue-and-groove waferboard (including OSB). Prices prior to 1984 delivered Chicago; prices thereafter are net f.o.b. North Central mill. Data from Random Lengths (Richards 1987).

9-7 ORIENTED-STRAND LUMBER

As mentioned in section 4-5, the plant will be arranged to permit manufacture of 32-foot-long, 1.5-inch-thick oriented-strand lumber. Because the technical problems of manufacture and the likely properties of such lumber are as yet undetermined, it is premature to define markets, price, and distribution methods. Obviously, manufacture of oriented-strand lumber would be undertaken only if the obtainable price per ton favored such production over sheathing or decking.

9-8 PULP CHIPS

Production of pulp chips will be modest (table 9-1), and it is assumed the entire output will be sold to a pulp mill near Missoula, MT, at $22 per unit weighing 2,400 pounds ovendry. This price corresponds to $18.33/ton, ovendry basis, net f.o.b. the Libby-Troy plant. The price was developed based on information obtained from sawmill operators currently selling chips in Montana and northern Idaho.

9-9 PARTICLEBOARD FURNISH

It is assumed that planer shavings and other material suitable for particleboard furnish and excess to plant fuel needs will be sold to the large particleboard plant in Missoula. Return on wood sold for this purpose is nominal. To be conservative, a price of $1/ton, ovendry-weight basis, net f.o.b. the Libby-Troy plant, loaded in cars or trucks, is used in this feasibility analysis.

9-10 REFERENCES

Koch, Peter; Springate, Norman C. 1983. Hardwood structural flakeboard—development of the industry in North America. Journal of Forestry. 81(3): 160-161.

Richards, Terri L., ed. 1987. Random lengths 1986 yearbook. Vol. 22. Eugene, OR: Random Lengths Publications, Inc. 202 p.

CHAPTER 10: CASH-FLOW ANALYSIS AND RETURN ON INVESTMENT

CONTENTS

10-1 INTRODUCTION

As outlined in previous chapters, we believe that the processes described for the proposed integrated plant are technically feasible. We also believe that the Libby-Troy procurement area at this time offers sufficient sub-sawlog-size, marginal sawlog-size, and dead lodgepole pine timber—together with trees of associated species of less than sawlog quality, to support the proposed plant.

Chapter 7 estimates operating costs and capital requirement, and delineates business assumptions related to economic analysis of the proposed enterprise.

This final chapter estimates the return on investment from this integrated multiproduct facility.

As previously noted (fig. 3-8), the facility is designed to annually process 200,000 tons of stemwood (ovendry-weight basis) from currently unmerchantable trees—mostly lodgepole pines 3 to 7 inches in d.b.h. Several manufacturing centers (fig. 5-2) will be integrated to produce the following products:

- market OSB (oriented-strand board)
- fabricated joists
- edge-glued lumber panels
- studs
- tree props and fence rails
- pulp chips
- particleboard furnish

The products are described in chapter 3 and in appendix III. The projected sales volume of each is shown in table 9-1.

The facility will generate an estimated $40 million in revenue in its first year of full production (table 10-1), and will operate for 20 years. It will require $62 million in capital and have operating costs before depreciation of $30 million in the first year of full production. Estimates of capital requirements, operating costs, and revenues are discussed in chapters 6, 7, and 9, respectively.

10-2 CASH-FLOW: 50 PERCENT DEBT, 50 PERCENT EQUITY FINANCING

The financial analysis is based on the assumption that the project will be developed by a Fortune-500-type company, domestic or foreign, with a good credit rating and ready access to the financial markets. This was the basis of the financing arrangement outlined in chapter 7.

To summarize, a line of credit would be established to handle the construction activities and to provide working capital for the initial phases of plant operation. Long-term financing for the facility would consist of a $31 million bond issue at 10 percent interest, and a $31 million common stock issue. It was assumed that the construction loan and working capital credit line would be at 10 percent interest. Other costs associated with the issue of the bonds and stocks are discussed in chapter 7.

Projected after-tax cash-flows, based on 50 percent equity financing for the 20-year production period, are shown in table 10-1. Interest expense on the bond issue has been deducted from the total revenue to calculate taxable income, and bond principal repayment has been deducted from taxable income. The adjusted cash-flow, therefore, represents the cash-flow—after corporate income taxes—to equity investors.

This after-tax average annual return on the equity investment of $31 million is estimated at 25.1 percent over the 22-year life of the project (table 10-1).

Table 10-1—Cash-flow: 50 percent debt, 50 percent equity financing (totals and subtotals may not sum due to rounding)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Revenues								
Sales	$ 0	$ 0	$33,422,375	$39,915,865	$41,712,079	$43,589,122	$45,550,633	$47,600,411
Sale of assets								
Total revenues	0	0	33,422,375	39,915,865	41,712,079	43,589,122	45,550,633	47,600,411
Expenses								
Material costs	0	0	10,957,625	12,973,828	13,440,886	13,924,758	14,426,049	14,945,387
Labor costs	222,000	906,000	7,588,000	8,984,192	9,307,623	9,642,697	9,989,834	10,349,468
Supplies and services	0	0	806,006	1,670,045	1,730,167	1,792,453	1,856,981	1,923,832
Sales costs	0	437,500	875,000	906,500	939,134	972,943	1,007,969	1,044,256
Professional services & insurance	0	0	735,000	761,460	788,873	817,272	846,694	877,175
Property taxes	0	0	500,000	518,000	536,648	555,967	575,982	646,718
Utilities	0	0	1,491,000	1,544,676	1,600,284	1,657,895	1,717,579	1,779,412
Depreciation	0	0	6,574,461	11,064,608	7,994,325	5,809,117	4,244,176	4,252,889
Amortization	0	0	11,625	11,625	11,625	11,625	11,625	11,625
Interest	0	0	3,126,787	3,033,246	2,973,796	2,908,252	2,835,990	2,756,322
Total expenses	222,000	1,343,500	32,665,505	41,468,180	39,323,360	38,092,978	37,512,879	38,587,083
Taxable income (loss)	(222,000)	(1,343,500)	756,870	(1,552,315)	2,388,719	5,496,144	8,037,754	9,013,329
Adjustments to cash-flow								
Add: Stock sale	0	0	31,000,000	0	0	0	0	0
: Bond sale	0	0	31,000,000	0	0	0	0	0
: Construction loan draw	2,095,198	59,038,524	1,844,622	0	0	0	0	0
: Depreciation & amortization	0	0	6,586,086	11,076,233	8,005,950	5,820,742	4,255,801	4,264,514
Less: Construction costs & vehicles	(1,798,234)	(51,935,516)	0	0	0	0	0	(70,174)
: Bond principal payments	0	0	(526,077)	(580,000)	(639,450)	(704,994)	(777,256)	(856,924)
: Increase in accounts receivable	0	0	(3,183,083)	(143,239)	(149,684)	(156,420)	(163,459)	(170,815)
: Increase in log inventory	0	(1,374,646)	(1,756,104)	(112,707)	(116,764)	(120,968)	(125,323)	(129,834)
: Stock and bond issue expenses	0	(1,662,500)	0	0	0	0	0	0
: Construction loan payment	0	0	(62,978,343)	0	0	0	0	0
: Construction loan interest	(74,964)	(2,722,361)	0	0	0	0	0	0
Pretax cash-flow	0	0	2,743,970	8,687,972	9,488,770	10,334,504	11,227,517	12,050,095
Tax benefit (detriment)	90,465	547,476	(308,425)	632,568	(973,403)	(2,239,679)	(3,275,385)	(3,672,931)
After-tax cash-flow	90,465	547,476	2,435,546	9,320,541	8,515,367	8,094,825	7,952,132	8,377,164

(con.)

Table 10-1 (Con.)

	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16
Revenues								
Sales	$49,742,430	$51,980,839	$54,319,977	$56,764,376	$59,318,773	$61,988,118	$64,777,583	$67,692,574
Sale of assets								
Total revenues	49,742,430	51,980,839	54,319,977	56,764,376	59,318,773	61,988,118	64,777,583	67,692,574
Expenses								
Material costs	15,483,421	16,040,824	16,618,293	17,216,552	17,836,348	18,478,456	19,143,681	19,832,853
Labor costs	10,722,049	11,108,043	11,507,933	11,922,218	12,351,418	12,796,069	13,256,728	13,733,970
Supplies and services	1,993,090	2,064,841	2,139,176	2,216,186	2,295,969	2,378,624	2,464,254	2,552,967
Sales costs	1,081,849	1,120,795	1,161,144	1,202,945	1,246,251	1,291,116	1,337,596	1,385,750
Professional services & insurance	908,753	941,468	975,361	1,010,474	1,046,851	1,084,538	1,123,581	1,164,030
Property taxes	719,999	795,919	874,572	956,057	990,475	1,026,132	1,063,073	1,101,344
Utilities	1,843,470	1,909,835	1,978,589	2,049,819	2,123,612	2,200,062	2,279,264	2,361,318
Depreciation	4,257,007	2,301,083	348,752	348,752	361,460	367,468	356,748	350,316
Amortization	11,625	11,625	11,625	11,625	11,625	11,625	11,625	11,625
Interest	2,668,487	2,571,649	2,464,886	2,347,179	2,217,407	2,074,333	1,916,595	1,742,688
Total expenses	39,689,751	38,866,084	38,080,331	39,281,807	40,481,416	41,708,423	42,953,145	44,236,861
Taxable income (loss)	10,052,679	13,114,755	16,239,646	17,482,569	18,837,357	20,279,695	21,824,438	23,455,714
Adjustments to cash-flow								
Add: Stock sale	0	0	0	0	0	0	0	0
: Bond sale	0	0	0	0	0	0	0	0
: Construction loan draw	0	0	0	0	0	0	0	0
: Depreciation & amortization	4,268,632	2,312,708	360,377	360,377	373,085	379,093	368,373	361,941
Less: Construction costs & vehicles	0	0	0	0	(83,748)	0	0	0
: Bond principal payments	(944,759)	(1,041,597)	(1,148,360)	(1,266,067)	(1,395,839)	(1,538,913)	(1,696,651)	(1,870,558)
: Increase in accounts receivable	(178,502)	(186,534)	(194,928)	(203,700)	(212,866)	(222,445)	(232,455)	(242,916)
: Increase in log inventory	(134,508)	(139,351)	(144,367)	(149,565)	(154,949)	(160,527)	(166,306)	(172,293)
: Stock and bond issue expenses	0	0	0	0	0	0	0	0
: Construction loan payment	0	0	0	0	0	0	0	0
: Construction loan interest	0	0	0	0	0	0	0	0
Pretax cash-flow	13,063,542	14,059,982	15,112,367	16,223,614	17,363,039	18,736,902	20,097,398	21,531,888
Tax benefit (detriment)	(4,096,467)	(5,344,263)	(6,617,656)	(7,124,147)	(7,676,223)	(8,263,976)	(8,893,459)	(9,558,203)
After-tax cash-flow	8,967,075	8,715,719	8,494,711	9,099,467	9,686,816	10,472,926	11,203,940	11,973,684

(con.)

Table 10-1 (Con.)

	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Sale
Revenues							
Sales	$70,738,740	$73,921,983	$77,248,473	$80,724,654	$84,357,263	$88,153,340	$ 0
Sale of assets							374,928
Total revenues	70,738,740	73,921,983	77,248,473	80,724,654	84,357,263	88,153,340	374,928
Expenses							
Material costs	20,546,836	21,286,522	22,052,837	22,846,739	23,669,222	24,521,314	0
Labor costs	14,228,393	14,740,615	15,271,277	15,821,043	16,390,601	16,980,662	0
Supplies and services	2,644,874	2,740,089	2,838,733	2,940,927	3,046,800	3,156,485	0
Sales costs	1,435,637	1,487,320	1,540,863	1,596,334	1,653,803	1,713,339	0
Professional services & insurance	1,205,935	1,249,349	1,294,325	1,340,921	1,389,194	1,439,205	0
Property taxes	1,140,992	1,182,068	1,224,622	1,268,708	1,314,382	1,361,700	0
Utilities	2,446,325	2,534,393	2,625,631	2,720,154	2,818,080	2,919,530	0
Depreciation	350,316	357,235	356,159	343,366	335,690	335,690	3,919,489
Amortization	11,625	11,625	11,625	11,625	11,625	11,625	0
Interest	1,550,956	1,339,571	1,106,519	849,580	56,304	253,992	0
Total expenses	45,561,889	46,928,787	48,322,592	49,739,398	51,195,699	52,693,543	3,919,489
Taxable income (loss)	25,176,851	26,993,196	28,925,881	30,985,256	33,161,564	35,459,797	(3,544,561)
Adjustments to cash-flow							
Add: Stock sale	0	0	0	0	0	0	0
: Bond sale	0	0	0	0	0	0	0
: Construction loan draw	0	0	0	0	0	0	0
: Depreciation & amortization	361,941	368,860	367,784	354,991	347,315	347,315	3,919,489
Less: Construction costs & vehicles	0	0	0	(99,948)	0	0	0
: Bond principal payments	(2,062,290)	(2,273,675)	(2,506,727)	(2,763,666)	(3,046,942)	(3,359,254)	0
: Increase in accounts receivable	(253,847)	(265,270)	(277,207)	(289,682)	(302,717)	(316,340)	7,346,112
: Increase in log inventory	(178,496)	(184,922)	(191,579)	(198,476)	(205,621)	(213,023)	0
: Stock and bond issue expenses	0	0	0	0	0	0	0
: Construction loan payment	0	0	0	0	0	0	0
: Construction loan interest	0	0	0	0	0	0	0
Pretax cash-flow	23,044,159	24,638,190	26,318,152	27,988,476	29,953,599	31,918,496	7,721,040
Tax benefit (detriment)	(10,259,567)	(10,999,727)	(11,787,296)	(12,626,492)	(13,513,337)	(14,449,867)	1,444,409
After-tax cash-flow	12,784,592	13,638,462	14,530,856	15,361,984	16,440,261	17,468,628	9,165,448

10-3 CASH-FLOW: EXCLUDING FINANCING FLOWS

Because the return on investment varies as the project's financing varies, an additional analysis was performed using the traditional approach to capital budgeting as described by Brigham (1979). This method does not explicitly bring the project's financing into the cash-flow analysis. The traditional financial model employed can be simply described as:

Net cash-flow = net income + depreciation

An adjustment to cash-flow was also made in this traditional analysis to show prepayment of raw materials inventory and to carry accounts receivable.

Under the assumptions described here and in earlier chapters, the net cash-flows using the traditional model show a 16.8 percent average annual rate of return from the project after corporate income taxes over the project's 22-year life. The traditional method is displayed (table 10-2) primarily because it is the method commonly used internally by business firms.

As illustrated in the discussion of 50 percent debt financing (section 10-2), return to the equity investors can exceed the traditional method's return by a substantial amount if a sizable proportion of debt financing is used.

10-4 REFERENCE

Brigham, Eugene F. 1979. Financial management: theory and practice. 2d ed. Hinsdale, IL: The Dryden Press: chapter 11.

Table 10-2—Cash-flow: excluding financing flows (totals and subtotals may not sum due to rounding)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Revenues								
Sales	$ 0	$ 0	$33,422,375	$39,915,865	$41,712,079	$43,589,122	$45,550,633	$47,600,411
Sale of assets								
Total revenues	0	0	33,422,375	39,915,865	41,712,079	43,589,122	45,550,633	47,600,411
Expenses								
Material costs	0	0	10,957,625	12,973,828	13,440,886	13,924,758	14,426,049	14,945,387
Labor costs	222,000	906,000	7,588,000	8,984,192	9,307,623	9,642,697	9,989,834	10,349,468
Supplies and services	0	0	806,006	1,670,045	1,730,167	1,792,453	1,856,981	1,923,832
Sales costs	0	437,500	875,000	906,500	939,134	972,943	1,007,969	1,044,256
Professional services & insurance	0	0	735,000	761,460	788,873	817,272	846,694	877,175
Property taxes	0	0	500,000	518,000	536,648	555,967	575,982	646,718
Utilities	0	0	1,491,000	1,544,676	1,600,284	1,657,895	1,717,579	1,779,412
Depreciation	0	0	6,574,461	11,064,608	7,994,325	5,809,117	4,244,176	4,252,889
Amortization	0	0	11,625	11,625	11,625	11,625	11,625	11,625
Total expenses	222,000	1,343,500	29,538,718	38,434,934	36,349,564	35,184,726	34,676,888	35,830,761
Taxable income (loss)	(222,000)	(1,343,500)	3,883,657	1,480,931	5,362,515	8,404,397	10,873,745	11,769,650
Adjustments to cash-flow								
Add: Depreciation & amortization	0	0	6,586,086	11,076,233	8,005,950	5,820,742	4,255,801	4,264,514
Less: Construction costs & vehicles	(1,798,234)	(51,935,516)	0	0	0	0	0	(70,174)
: Increase in accounts receivable	0	0	(3,183,083)	(143,239)	(149,684)	(156,420)	(163,459)	(170,815)
: Increase in log inventory	0	(1,374,646)	(1,756,104)	(112,707)	(116,764)	(120,968)	(125,323)	(129,834)
Pretax cash-flow	(2,020,234)	(54,653,662)	5,530,556	12,301,218	13,102,016	13,947,750	14,840,763	15,663,341
Tax benefit (detriment)	90,465	547,476	(1,582,590)	(603,479)	(2,185,225)	(3,424,792)	(4,431,051)	(4,796,132)
After-tax cash-flow	(1,929,769)	(54,106,186)	3,947,966	11,697,739	10,916,791	10,522,958	10,409,712	10,867,209

(con.)

Table 10-2 (Con.)

	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16
Revenues								
Sales	$49,742,430	$51,980,839	$54,319,977	$56,764,376	$59,318,773	$61,988,118	$64,777,583	$67,692,574
Sale of assets								
Total revenues	49,742,430	51,980,839	54,319,977	56,764,376	59,318,773	61,988,118	64,777,583	67,692,574
Expenses								
Material costs	15,483,421	16,040,824	16,618,293	17,216,552	17,836,348	18,478,456	19,143,681	19,832,853
Labor costs	10,722,049	11,108,043	11,507,933	11,922,218	12,351,418	12,796,069	13,256,728	13,733,970
Supplies and services	1,993,090	2,064,841	2,139,176	2,216,186	2,295,969	2,378,624	2,464,254	2,552,967
Sales costs	1,081,849	1,120,795	1,161,144	1,202,945	1,246,251	1,291,116	1,337,596	1,385,750
Professional services & insurance	908,753	941,468	975,361	1,010,474	1,046,851	1,084,538	1,123,581	1,164,030
Property taxes	719,999	795,919	874,572	956,057	990,475	1,026,132	1,063,073	1,101,344
Utilities	1,843,470	1,909,835	1,978,589	2,049,819	2,123,612	2,200,062	2,279,264	2,361,318
Depreciation	4,257,007	2,301,083	348,752	348,752	361,460	367,468	356,748	350,316
Amortization	11,625	11,625	11,625	11,625	11,625	11,625	11,625	11,625
Total expenses	37,021,264	36,294,435	35,615,446	36,934,628	38,264,009	39,634,090	41,036,550	42,494,173
Taxable income (loss)	12,721,166	15,686,405	18,704,531	19,829,748	21,054,764	22,354,028	23,741,033	25,198,402
Adjustments to cash-flow								
Add: Depreciation & amortization	4,268,632	2,312,708	360,377	360,377	373,085	379,093	368,373	361,941
Less: Construction costs & vehicles	0	0	0	0	(83,748)	0	0	0
: Increase in accounts receivable	(178,502)	(186,534)	(194,928)	(203,700)	(212,866)	(222,445)	(232,455)	(242,916)
: Increase in log inventory	(134,508)	(139,351)	(144,367)	(149,565)	(154,949)	(160,527)	(166,306)	(172,293)
Pretax cash-flow	16,676,788	17,673,228	18,725,613	19,836,860	20,976,285	22,350,148	23,710,644	25,145,134
Tax benefit (detriment)	(5,183,875)	(6,392,210)	(7,622,096)	(8,080,622)	(8,579,816)	(9,109,266)	(9,674,471)	(10,268,349)
After-tax cash-flow	11,492,913	11,281,018	11,103,516	11,756,238	12,396,469	13,240,881	14,036,173	14,876,785

(con.)

Table 10-2 (Con.)

	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Sale
Revenues							
Sales	$70,738,740	$73,921,983	$77,248,473	$80,724,654	$84,357,263	$88,153,340	$ 0
Sale of assets							374,928
Total revenues	70,738,740	73,921,983	77,248,473	80,724,654	84,357,263	88,153,340	374,928
Expenses							
Material costs	20,546,836	21,286,522	22,052,837	22,846,739	23,669,222	24,521,314	0
Labor costs	14,228,393	14,740,615	15,271,277	15,821,043	16,390,601	16,980,662	0
Supplies and services	2,644,874	2,740,089	2,838,733	2,940,927	3,046,800	3,156,485	0
Sales costs	1,435,637	1,487,320	1,540,863	1,596,334	1,653,803	1,713,339	0
Professional services & insurance	1,205,935	1,249,349	1,294,325	1,340,921	1,389,194	1,439,205	0
Property taxes	1,140,992	1,182,068	1,224,622	1,268,708	1,314,382	1,361,700	0
Utilities	2,446,325	2,534,393	2,625,631	2,720,154	2,818,080	2,919,530	0
Depreciation	350,316	357,235	356,159	343,366	335,690	335,690	3,919,489
Amortization	11,625	11,625	11,625	11,625	11,625	11,625	0
Total expenses	44,010,933	45,589,216	47,216,073	48,889,818	50,629,396	52,439,550	3,919,489
Taxable income (loss)	26,727,807	28,332,767	30,032,400	31,834,836	33,727,868	35,713,790	(3,544,561)
Adjustments to cash-flow							
Add: Depreciation & amortization	361,941	368,860	367,784	354,991	347,315	347,315	3,919,489
Less: Construction costs & vehicles	0	0	0	(99,948)	0	0	0
: Increase in accounts receivable	(253,847)	(265,270)	(277,207)	(289,682)	(302,717)	(316,340)	7,346,112
: Increase in log inventory	(178,496)	(184,922)	(191,579)	(198,476)	(205,621)	(213,023)	0
Pretax cash-flow	26,657,405	28,251,436	29,931,398	31,601,722	33,566,845	35,531,742	7,721,040
Tax benefit (detriment)	(10,891,581)	(11,545,603)	(12,238,203)	(12,972,696)	(13,744,106)	(14,553,369)	(1,444,409)
After-tax cash-flow	15,765,824	16,705,833	17,693,195	18,629,026	19,822,738	20,978,373	9,165,448

APPENDIX I: NUMBERS OF LIVE LODGEPOLE PINE TREES AND GROWING STOCK VOLUME ON COMMERCIAL TIMBER LAND IN 21 WESTERN MONTANA COUNTIES, BY TREE DIAMETER CLASS AND OWNERSHIP

Growing stock volume is cubic feet of stemwood in live lodgepole pine trees 5 inches in d.b.h. and larger from a 1-foot-high stump to a 4-inch top diameter measured outside bark. Data, based on survey information collected from 1966 to 1980, are from a special tabulation compiled by the Forest Survey Research Unit, Intermountain Research Station, USDA Forest Service, Ogden, UT.

From stump top to apical tip, typical stemwood volume of a lodgepole pine 2 inches in d.b.h. is about 1/3 ft^3; that of a 4-inch tree to apical tip is about 1 1/4 ft^3.

Diameter classes (measured at breast height, outside bark) span 1.9 inches; for example, the 4-inch class spans from 3.0 to 4.9 inches.

Table I-1—Number of trees and growing stock volume

Diameter class	Number of trees			Growing stock volume ft^3		
	State/ private	National Forest	Total	State/ private	National Forest	Total
Inches			Beaverhead County, MT			
2	7,674,556	60,938,115	68,612,671	—	—	—
4	4,756,398	73,350,340	78,106,738	—	—	—
6	2,534,448	65,423,370	67,957,818	11,118,582	183,583,104	194,701,686
8	1,256,671	38,132,698	39,389,369	10,362,396	282,837,459	293,199,855
10	713,999	16,342,998	17,056,997	9,618,581	207,105,451	216,724,032
12	368,023	6,422,772	6,790,795	7,585,974	122,219,620	129,805,594
14	134,439	2,579,652	2,714,091	3,951,933	70,364,320	74,316,253
16	82,505	460,733	543,238	3,256,227	17,006,950	20,263,177
18	23,598	136,444	160,042	1,043,886	6,472,936	7,516,822
20	7,102	30,431	37,533	400,860	1,563,298	1,964,158
22	2,362	12,972	15,334	166,371	652,502	818,873
24	0	31,702	31,702	0	2,429,385	2,429,385
26	0	2,528	2,528	0	203,578	203,578
28	0	2,665	2,665	0	306,671	306,671
30+	0	4,732	4,732	0	777,133	777,133
Total	17,554,101	263,872,152	281,426,253	47,504,810	895,522,407	943,027,217
Inches			Broadwater County, MT			
2	2,771,971	3,750,842	6,522,813	—	—	—
4	597,491	5,583,298	6,180,789	—	—	—
6	417,872	7,203,789	7,621,661	1,661,991	19,688,993	21,350,984
8	259,987	4,683,299	4,943,286	1,898,541	33,770,479	35,669,020
10	64,433	2,171,715	2,236,148	750,111	27,228,963	27,979,074
12	33,084	912,121	945,205	478,326	15,968,847	16,447,173
14	10,182	286,785	296,967	222,952	7,021,399	7,244,351
16	3,341	106,539	109,880	92,787	3,457,019	3,549,806
18	719	37,653	38,372	37,311	1,545,865	1,583,176
20	691	8,707	9,398	40,592	448,998	489,590
22	0	7,060	7,060	0	444,442	444,442
24	0	0	0	0	0	0
26	0	0	0	0	0	0
28	0	0	0	0	0	0
30+	0	0	0	0	0	0
Total	4,159,771	24,751,808	28,911,579	5,182,611	109,575,005	114,757,616

(con.)

Table I-1 (Con.)

Diameter class	Number of trees: State/ private	Number of trees: National Forest	Number of trees: Total	Growing stock volume ft³: State/ private	Growing stock volume ft³: National Forest	Growing stock volume ft³: Total
Inches			Carbon County, MT			
2	1,973,553	5,383,238	7,356,791	—	—	—
4	862,752	7,900,920	8,763,672	—	—	—
6	229,521	4,618,607	4,848,128	700,188	9,686,627	10,386,815
8	34,846	2,072,877	2,107,723	221,802	10,841,962	11,063,764
10	35,547	735,299	770,846	361,048	7,149,231	7,510,279
12	23,749	295,571	319,320	368,575	4,280,189	4,648,764
14	14,649	91,641	106,290	286,151	2,144,246	2,430,397
16	4,618	33,718	38,336	116,686	1,025,748	1,142,434
18	0	18,719	18,719	0	815,494	815,494
20	0	4,193	4,193	0	237,098	237,098
22	0	1,404	1,404	0	103,892	103,892
24	0	44	44	0	3,452	3,452
26	0	210	210	0	18,310	18,310
28	0	887	887	0	70,669	70,669
30+	0	0	0	0	0	0
Total	3,179,235	21,157,328	24,336,563	2,054,450	36,376,918	38,431,368
Inches			Deerlodge County, MT			
2	10,448,099	7,336,401	17,784,500	—	—	—
4	6,327,157	9,745,823	16,072,980	—	—	—
6	3,057,107	8,354,621	11,411,728	13,442,243	23,821,080	37,263,323
8	1,493,895	4,737,408	6,231,303	12,358,051	35,619,698	47,977,749
10	841,762	2,016,635	2,858,397	11,414,177	26,162,938	37,577,115
12	428,380	732,358	1,160,738	8,861,101	14,209,647	23,070,748
14	156,269	261,714	417,983	4,607,301	7,157,410	11,764,711
16	98,312	51,045	149,357	3,867,640	1,860,445	5,728,085
18	28,182	12,343	40,525	1,241,540	579,999	1,821,539
20	8,427	4,121	12,548	474,494	228,430	702,924
22	2,701	1,408	4,109	190,241	70,851	261,092
24	0	2,626	2,626	0	205,890	205,890
26	0	284	284	0	24,412	24,412
28	0	123	123	0	14,191	14,191
30+	0	422	422	0	69,576	69,576
Total	22,890,291	33,257,332	56,147,623	56,456,788	110,024,567	166,481,355
Inches			Flathead County, MT			
2	33,126,047	35,721,959	68,848,006	—	—	—
4	34,974,566	52,731,730	87,706,296	—	—	—
6	17,529,502	34,475,806	52,005,308	86,386,743	95,401,804	181,788,547
8	7,997,966	18,455,405	26,453,371	72,196,886	150,105,600	222,302,486
10	3,260,056	7,031,519	10,291,575	49,226,542	99,527,189	148,753,731
12	1,011,455	3,133,559	4,145,014	22,774,798	65,245,116	88,019,914
14	442,101	1,402,830	1,844,931	13,785,327	39,780,877	53,566,204
16	71,333	467,798	539,131	3,139,477	16,840,447	19,979,924
18	12,343	127,204	139,547	676,127	6,101,630	6,777,757
20	5,014	20,018	25,032	315,449	1,172,549	1,487,998
22	864	4,783	5,647	68,758	484,571	553,329
24	1,409	256	1,665	106,412	29,195	135,607
26	0	0	0	0	0	0
28	0	0	0	0	0	0
30+	0	0	0	0	0	0
Total	98,432,656	153,572,867	252,005,523	248,676,519	474,688,978	723,365,497

(con.)

Table I-1 (Con.)

Diameter class	Number of trees			Growing stock volume ft^3		
	State/ private	National Forest	Total	State/ private	National Forest	Total
Inches			**Gallatin County, MT**			
2	4,995,847	12,407,562	17,403,409	—	—	—
4	5,160,058	17,609,512	22,769,570	—	—	—
6	3,065,585	17,602,565	20,668,150	14,804,556	53,965,120	68,769,676
8	2,913,361	10,648,721	13,562,082	23,424,255	83,328,204	106,752,459
10	1,774,760	7,538,964	9,313,724	23,355,177	102,079,012	125,434,189
12	710,360	4,479,081	5,189,441	14,099,933	90,364,696	104,464,629
14	395,340	2,482,096	2,877,436	10,895,984	70,308,889	81,204,873
16	131,179	915,244	1,046,423	4,563,199	34,254,711	38,817,910
18	64,444	485,995	550,439	3,052,045	22,154,598	25,206,643
20	22,375	183,596	205,971	1,168,616	11,795,475	12,964,091
22	9,710	37,904	47,614	690,897	2,838,535	3,529,432
24	0	7,406	7,406	0	578,288	578,228
26	0	4,173	4,173	0	366,563	366,563
28	0	2,338	2,338	0	221,023	221,023
30+	0	0	0	0	39	39
Total	19,243,019	74,405,157	93,648,176	96,054,662	472,255,153	568,309,815
Inches			**Granite County, MT**			
2	17,520,886	25,404,217	42,925,103	—	—	—
4	8,449,153	45,508,604	53,957,757	—	—	—
6	4,416,579	42,727,634	47,144,213	21,303,581	131,448,248	152,751,829
8	2,502,814	24,056,373	26,559,187	21,981,755	194,221,172	216,202,927
10	899,567	10,025,809	10,925,376	13,206,729	141,091,320	154,298,049
12	302,775	3,519,475	3,822,250	6,372,288	74,193,442	80,565,730
14	121,701	980,450	1,102,151	3,636,188	28,568,582	32,204,770
16	29,306	277,782	307,088	1,029,887	10,783,123	11,813,010
18	16,974	52,152	69,126	740,794	2,479,469	3,220,263
20	3,613	29,376	32,989	182,292	1,841,035	2,023,327
22	651	2,331	2,982	46,906	182,913	229,819
24	1,386	1,252	2,638	93,428	142,562	235,990
26	1,043	866	1,909	71,536	96,891	168,427
28	0	0	0	0	0	0
30+	706	0	706	94,289	0	94,289
Total	34,267,154	152,586,321	186,853,475	68,759,673	585,048,757	653,808,430
Inches			**Jefferson County, MT**			
2	2,281,435	16,305,672	18,587,107	—	—	—
4	875,805	26,185,025	27,060,830	—	—	—
6	912,113	26,153,020	27,065,133	3,806,958	77,929,700	81,736,658
8	498,147	16,379,494	16,877,641	3,672,051	127,436,952	131,109,003
10	136,697	7,294,411	7,431,108	1,619,240	99,349,545	100,968,785
12	54,637	2,650,256	2,704,893	842,820	52,885,644	53,728,464
14	33,100	839,186	872,286	721,451	23,522,774	24,244,225
16	4,725	230,005	234,730	143,121	8,163,683	8,306,804
18	2,907	53,561	56,468	150,771	2,410,140	2,560,911
20	1,472	26,152	27,624	86,461	1,584,245	1,670,706
22	0	3,628	3,628	0	240,104	240,104
24	0	0	0	0	0	0
26	0	1,449	1,449	0	162,093	162,093
28	0	0	0	0	0	0
30+	0	0	0	0	0	0
Total	4,801,038	96,121,859	100,922,897	11,042,873	393,684,880	404,727,753

(con.)

Table I-1 (Con.)

Diameter class	Number of trees			Growing stock volume ft³		
	State/ private	National Forest	Total	State/ private	National Forest	Total
Inches			Lake County, MT			
2	2,251,115	3,651,931	5,903,046	—	—	—
4	2,410,093	5,393,586	7,803,679	—	—	—
6	2,564,199	3,473,752	6,037,951	12,885,735	9,359,817	22,245,552
8	1,610,891	1,861,561	3,472,452	14,625,369	15,292,448	29,917,817
10	561,115	743,517	1,304,632	8,114,254	10,746,200	18,860,454
12	260,635	337,860	598,495	5,774,142	7,122,908	12,897,050
14	75,085	163,612	238,697	2,373,831	4,776,416	7,150,247
16	22,300	50,390	72,690	877,901	1,820,727	2,698,628
18	4,409	14,114	18,523	215,381	662,480	877,861
20	4,971	1,560	6,531	331,005	94,027	425,032
22	2,783	351	3,134	212,324	37,347	249,671
24	0	1	1	0	101	101
26	0	0	0	0	0	0
28	0	0	0	0	0	0
30+	0	0	0	0	0	0
Total	9,767,596	15,692,235	25,459,831	45,409,942	49,912,471	95,322,413
Inches			Lewis and Clark County, MT			
2	16,316,841	25,093,045	41,409,886	—	—	—
4	6,195,210	35,694,353	41,889,563	—	—	—
6	4,383,421	37,594,940	41,978,361	19,563,774	103,984,920	123,548,694
8	2,510,012	22,138,337	24,648,349	20,124,699	162,295,504	182,420,203
10	814,329	9,466,319	10,280,648	11,001,231	119,690,731	130,691,962
12	300,185	3,992,264	4,292,449	5,542,057	71,209,738	76,751,795
14	137,094	1,200,232	1,337,326	3,517,154	29,967,980	33,485,134
16	27,545	411,724	439,269	916,200	13,819,864	14,736,064
18	12,973	147,461	160,434	620,691	6,093,971	6,714,662
20	6,654	32,569	39,223	375,480	1,739,820	2,115,300
22	214	19,851	20,065	15,421	1,347,760	1,363,181
24	513	307	820	34,600	18,923	53,523
26	251	199	450	17,220	17,645	34,865
28	0	0	0	0	0	0
30+	261	0	261	34,919	0	34,919
Total	30,705,503	135,791,601	166,497,104	61,763,446	510,186,856	571,950,302
Inches			Lincoln County, MT			
2	27,745,757	32,920,429	60,666,186	—	—	—
4	28,002,686	78,215,244	106,217,930	—	—	—
6	14,553,466	72,408,716	86,962,182	70,952,311	233,006,937	303,959,248
8	6,211,449	38,097,171	44,308,620	55,568,651	330,286,633	385,855,284
10	2,294,163	15,899,375	18,193,538	34,103,404	229,091,836	263,195,240
12	602,682	6,060,588	6,663,270	13,554,824	125,348,313	138,903,137
14	269,305	1,765,928	2,035,233	8,512,0135	46,975,408	55,487,421
16	48,443	523,057	571,500	2,179,469	21,265,463	23,444,932
18	11,328	149,023	160,351	619,923	8,588,889	9,208,812
20	3,109	64,104	67,213	195,601	4,354,396	4,549,997
22	943	15,732	16,675	75,075	1,002,952	1,078,027
24	432	0	432	32,653	0	32,653
26	0	0	0	0	0	0
28	0	10	10	0	1,944	1,944
30+	0	0	0	0	0	0
Total	79,743,763	246,119,377	325,863,140	185,793,924	999,922,771	1,185,716,695

(con.)

Table I-1 (Con.)

Diameter class	Number of trees: State/ private	Number of trees: National Forest	Number of trees: Total	Growing stock volume ft³: State/ private	Growing stock volume ft³: National Forest	Growing stock volume ft³: Total
Inches			**Madison County, MT**			
2	13,830,071	23,525,480	37,355,551	—	—	—
4	8,395,207	28,832,272	37,227,479	—	—	—
6	4,512,839	26,186,989	30,699,828	19,779,988	74,046,852	93,826,840
8	2,210,582	15,615,438	17,826,020	18,312,224	116,266,035	134,578,259
10	1,261,251	7,001,660	8,262,911	17,121,365	89,400,801	106,522,166
12	650,441	2,937,361	3,587,802	13,498,009	56,257,124	69,755,133
14	245,072	1,216,449	1,461,521	7,249,848	33,096,600	40,346,448
16	152,592	299,629	452,221	6,053,409	10,868,249	16,921,658
18	42,799	112,092	154,891	1,911,876	5,033,715	6,945,591
20	13,266	30,324	43,590	750,588	1,801,670	2,552,258
22	4,566	16,253	20,819	321,574	941,588	1,263,162
24	0	10,390	10,390	0	818,195	818,195
26	0	1,653	1,653	0	142,454	142,454
28	0	784	784	0	85,786	85,786
30+	0	1,578	1,578	0	259,187	259,187
Total	31,318,686	105,788,352	137,107,038	84,998,881	389,018,256	474,017,137
Inches			**Meagher County, MT**			
2	1,540,517	31,004,861	32,545,378	—	—	—
4	5,430,646	35,670,325	41,100,971	—	—	—
6	3,173,595	29,276,139	32,449,734	15,001,471	83,912,561	98,914,032
8	3,656,135	16,543,618	20,199,753	33,244,053	125,617,280	158,861,333
10	1,784,406	7,335,367	9,119,773	26,264,011	93,442,786	119,706,797
12	532,687	3,435,814	3,968,501	10,978,946	65,503,220	76,482,166
14	167,643	1,077,919	1,245,562	4,472,882	28,581,114	33,053,996
16	75,438	418,968	494,406	2,601,695	15,544,892	18,146,587
18	47,861	91,024	138,885	2,064,406	4,027,944	6,092,350
20	7,867	32,633	40,500	343,887	1,952,524	2,296,411
22	5,866	8,704	14,570	290,741	668,179	958,920
24	0	1,580	1,580	0	90,585	90,585
26	0	1,554	1,554	0	137,462	137,462
28	0	33	33	0	3,198	3,198
30+	0	0	0	0	0	0
Total	16,422,661	124,898,539	141,321,200	95,262,092	419,481,745	514,743,837
Inches			**Mineral County, MT**			
2	2,639,843	10,240,895	12,880,738	—	—	—
4	2,326,800	24,796,336	27,123,136	—	—	—
6	2,256,436	28,187,956	30,444,392	11,499,997	90,587,460	102,087,457
8	1,505,805	14,690,349	16,196,154	13,860,590	130,311,912	144,172,502
10	628,885	5,751,001	6,379,886	9,036,597	86,426,752	95,463,349
12	199,552	2,358,756	2,558,308	4,278,661	52,814,242	57,092,903
14	90,357	645,901	736,258	2,677,912	19,699,462	22,377,374
16	23,761	232,045	255,806	889,478	10,254,916	11,144,394
18	6,814	34,475	41,289	320,112	1,894,902	2,215,014
20	1,003	8,516	9,519	54,314	596,770	651,084
22	712	5,177	5,889	45,538	413,838	459,376
24	0	3,736	3,736	0	425,363	425,363
26	0	0	0	0	0	0
28	0	0	0	0	0	0
30+	0	0	0	0	0	0
Total	9,679,968	86,955,143	96,635,111	42,663,199	393,425,617	436,088,816

(con.)

Table I-1 (Con.)

Diameter class	Number of trees: State/ private	National Forest	Total	Growing stock volume ft³: State/ private	National Forest	Total
Inches			Missoula County, MT			
2	19,857,177	9,311,080	29,168,257	—	—	—
4	16,314,967	19,885,125	36,200,092	—	—	—
6	14,287,634	21,688,208	35,975,842	71,866,144	68,810,402	140,676,546
8	8,630,893	11,431,454	20,062,347	80,286,020	100,948,786	181,234,806
10	3,390,307	4,599,047	7,989,354	49,184,547	68,977,193	118,161,740
12	1,010,971	1,883,688	2,894,659	21,534,106	42,263,739	63,797,845
14	470,845	570,619	1,041,464	13,773,568	17,276,608	31,050,176
16	110,834	208,906	319,740	3,991,533	9,024,412	13,015,945
18	32,221	34,022	66,243	1,484,016	1,818,232	3,302,248
20	5,815	8,271	14,086	314,985	578,307	893,292
22	3,447	4,752	8,199	220,364	382,673	603,037
24	0	2,316	2,316	0	263,689	263,689
26	0	0	0	0	0	0
28	0	0	0	0	0	0
30+	0	0	0	0	0	0
Total	64,115,111	69,627,488	133,742,599	242,655,283	310,344,041	552,999,324
Inches			Park County, MT			
2	2,830,273	10,189,267	13,019,540	—	—	—
4	2,352,599	13,747,994	16,100,593	—	—	—
6	1,897,103	14,302,980	16,200,083	9,405,821	43,672,366	53,078,187
8	1,803,390	9,466,621	11,270,011	14,586,837	74,323,062	88,909,899
10	1,116,156	7,869,776	8,985,932	14,984,302	106,495,348	121,479,650
12	504,498	4,922,229	5,426,727	9,986,625	99,144,744	109,131,369
14	278,397	2,791,703	3,070,100	7,887,462	79,585,256	87,472,718
16	85,419	1,017,836	1,103,255	3,018,863	38,617,044	41,635,907
18	52,266	549,198	601,464	2,397,909	25,287,823	27,685,732
20	18,696	209,842	228,538	988,856	13,313,142	14,301,998
22	7,269	40,295	47,564	509,998	3,034,924	3,544,922
24	0	9,368	9,368	0	731,329	731,329
26	0	6,674	6,674	0	585,143	585,143
28	0	3,020	3,020	0	284,545	284,545
30+	0	0	0	0	0	0
Total	10,946,066	65,126,803	76,072,869	63,766,673	485,074,726	548,841,399
Inches			Powell County, MT			
2	30,252,971	10,985,097	41,238,068	—	—	—
4	16,043,390	19,281,171	35,324,561	—	—	—
6	8,500,467	22,198,959	30,699,426	40,783,336	64,946,824	105,730,160
8	4,827,217	13,282,163	18,109,380	42,514,710	103,008,768	145,523,478
10	1,782,268	5,686,541	7,468,809	26,045,122	76,466,838	102,511,960
12	630,808	2,220,130	2,850,938	13,338,692	42,584,356	55,923,048
14	244,177	643,635	887,812	7,299,441	17,278,835	24,578,276
16	59,439	215,627	275,066	2,116,938	7,753,467	9,870,405
18	37,893	64,976	102,869	1,668,719	2,799,568	4,468,287
20	7,057	17,307	24,364	355,863	964,933	1,320,796
22	1,957	9,118	11,075	140,860	632,472	773,332
24	2,789	486	3,275	187,986	55,403	243,389
26	1,303	156	1,459	89,390	17,479	106,869
28	0	0	0	0	0	0
30+	1,420	0	1,420	189,719	0	189,719
Total	62,393,156	74,605,366	136,998,522	134,730,776	316,508,943	451,239,719

(con.)

Table I-1 (Con.)

Diameter class	Number of trees: State/private	Number of trees: National Forest	Number of trees: Total	Growing stock volume ft³: State/private	Growing stock volume ft³: National Forest	Growing stock volume ft³: Total
Inches			**Ravalli County, MT**			
2	777,959	7,207,594	7,985,553	—	—	—
4	481,529	12,712,453	13,193,982	—	—	—
6	505,748	17,175,557	17,681,305	2,412,813	55,187,584	57,600,397
8	284,443	12,289,347	12,573,790	2,564,736	101,811,822	104,376,558
10	173,843	6,136,190	6,310,033	2,691,407	91,606,180	94,297,587
12	144,858	2,182,187	2,327,045	3,030,046	49,261,470	52,291,516
14	35,661	462,171	497,832	1,079,036	14,241,169	15,320,205
16	3,602	100,812	104,414	141,986	4,170,704	4,312,690
18	5,427	41,910	47,337	204,294	2,447,193	2,651,487
20	1,868	4,902	6,770	101,481	450,443	551,924
22	0	0	0	0	0	0
24	0	1,605	1,605	0	239,947	239,947
26	0	1,117	1,117	0	144,950	144,950
28	0	0	0	0	0	0
30+	0	0	0	0	0	0
Total	2,414,938	58,315,845	60,730,783	12,225,799	319,561,462	331,787,261
Inches			**Sanders County, MT**			
2	4,911,418	15,931,695	20,843,113	—	—	—
4	3,596,967	38,800,363	42,397,330	—	—	—
6	4,774,581	39,815,018	44,589,599	24,562,918	129,084,108	153,647,026
8	3,404,108	20,755,188	24,159,296	31,447,468	182,592,953	214,040,421
10	1,170,727	8,277,911	9,448,638	17,183,812	122,034,982	139,218,794
12	453,438	3,294,347	3,747,785	10,179,138	71,290,880	81,470,018
14	165,489	927,548	1,093,037	5,311,933	26,184,872	31,496,805
16	40,462	310,115	350,577	1,546,860	13,347,245	14,894,105
18	6,463	67,109	73,572	302,624	3,836,231	4,138,855
20	14,384	25,136	39,520	1,004,389	1,725,473	2,729,862
22	3,939	7,253	11,192	297,869	539,343	837,212
24	0	2,923	2,923	0	332,772	332,772
26	0	0	0	0	0	0
28	0	0	0	0	513	513
30+	0	0	0	0	0	0
Total	18,541,976	128,214,606	146,756,582	91,837,011	550,969,372	642,806,383
Inches			**Silver Bow County, MT**			
2	6,322,043	7,837,125	14,159,168	—	—	—
4	3,819,151	12,145,949	15,965,100	—	—	—
6	1,770,257	11,654,106	13,424,363	7,778,531	35,257,688	43,036,219
8	869,169	7,093,263	7,962,432	7,154,068	55,574,242	62,728,310
10	490,867	3,096,122	3,586,989	6,619,259	42,449,694	49,068,953
12	248,122	1,084,357	1,332,479	5,099,105	22,076,945	27,176,050
14	89,001	343,471	432,472	2,611,855	9,838,024	12,449,879
16	55,528	79,767	135,295	2,176,062	2,899,648	5,075,710
18	16,010	18,747	34,757	700,748	880,387	1,581,135
20	4,672	9,181	13,853	262,907	561,823	824,730
22	1,482	373	1,855	104,373	18,789	123,162
24	0	932	932	0	65,824	65,824
26	0	499	499	0	53,869	53,869
28	0	227	227	0	26,221	26,221
30+	0	113	113	0	18,913	18,913
Total	13,686,302	43,364,232	57,050,534	32,506,908	169,722,067	202,228,975

(con.)

Table I-1 (Con.)

Diameter class	Number of trees			Growing stock volume ft^3		
	State/ private	National Forest	Total	State/ private	National Forest	Total
Inches			Stillwater County, MT			
2	1,667,852	4,435,059	6,102,911	—	—	—
4	723,394	7,453,030	8,176,424	—	—	—
6	188,614	3,312,249	3,500,863	573,179	6,423,126	6,996,305
8	23,904	1,373,623	1,397,527	151,346	6,866,352	7,017,698
10	30,701	461,598	492,299	321,136	4,323,529	4,644,665
12	15,551	164,552	180,103	240,596	2,139,667	2,380,263
14	10,194	43,655	53,849	189,484	913,037	1,102,521
16	3,666	9,841	13,507	90,849	250,216	341,065
18	0	3,523	3,523	0	147,979	147,979
20	0	774	774	0	38,774	38,774
22	0	0	0	0	0	0
24	0	0	0	0	0	0
26	0	0	0	0	0	0
28	0	356	356	0	28,340	28,340
30+	0	0	0	0	0	0
Total	2,663,876	17,258,260	19,922,136	1,566,590	21,131,020	22,697,610

APPENDIX II: COST OF HARVEST AND LOADING

II-1 EQUIPMENT HOURLY COSTS, NOT INCLUDING LABOR

Assumptions

For all equipment considered here, depreciation is calculated on a straight-line basis over a 10,000-hour life (5 years), with zero salvage value (except for the miscellaneous support equipment). Repair, maintenance, and fuel and oil costs are assumed equal to depreciation costs. Interest on investment is assumed at 15 percent, and insurance and taxes at 5 percent, of average value of investment (AVI), where:

AVI = ([purchase price – salvage value] x 6)/(2 x 5).

Morbell or Bobcat class feller buncher ($90,000 cost; AVI = $54,000)

Depreciation	$9.00	
Repairs, maintenance, fuel, and oil	9.00	
Interest, insurance, and taxes	5.40	
Operating cost/hour		$23.40

Timbco class steep-slope feller buncher ($220,000 cost; AVI = $132,000)

Depreciation	$22.00	
Repairs, maintenance, fuel, and oil	22.00	
Interest, insurance, and taxes	13.20	
Operating cost/hour		$57.20

Grapple skidder of JD-540 class ($85,000 cost; salvage value = $15,000; AVI = $57,000)

Depreciation	$7.00	
Repairs, maintance, fuel, and oil	7.00	
Interest, insurance, and taxes	5.70	
Operating cost/hour		$19.70

Forwarder, timberjack 540 class ($200,000 cost; AVI = $120,000)

Depreciation	$20.00	
Repairs, maintenance, fuel, and oil	20.00	
Interest, insurance, and taxes	12.00	
Operating cost/hour		$52.00

Loader, hydraulic, self-propelled ($90,000 cost; AVI = $54,000)

Depreciation	$9.00	
Repairs, maintenance, fuel, and oil	9.00	
Interest, insurance, and taxes	5.40	
Operating cost/hour		$23.40

Miscellaneous support equipment: service truck, landing crawler tractor, crew truck, etc. ($65,000 cost; salvage value = $25,000; AVI = $49,000)

Depreciation	$4.00	
Repairs, maintenance, fuel, and oil	4.00	
Interest, insurance, and taxes	4.90	
Operating cost/hour		$12.90

II-2 HOURLY COSTS FOR FIVE SYSTEMS, EQUIPMENT ONLY

SYSTEM 1			
	Morbell or Bobcat feller buncher	$23.40	
	Three grapple skidders (1/4-mile skid)	59.10	
	Loader	23.40	
	Support equipment	12.90	
	System cost/hour		$118.80
SYSTEM 2			
	Same as system 1, except that because of short (1/8-mile) skidding distance only two grapple skidders are required		
	System cost/hour		$99.10
SYSTEM 3			
	Same as system 1, except with half the loader cost (that is, the loader serves two systems)		
	System cost/hour		$107.10
SYSTEM 4			
	Timbco feller buncher	$57.20	
	Forwarder (1/4 to 1/2 mile)	52.00	
	Loader	23.40	
	Support equipment	12.90	
	System cost/hour		$145.50
SYSTEM 5			
	Same as system 4, except with half the loader cost (that is, the loader serves two systems)		
	System cost/hour		$133.80

Hourly Operator Wage Costs

Workman's compensation costs are 38 percent of basic wages, and other payroll costs are 12 percent, for a total of 50 percent of basic wage costs.

LOW		
	Basic wage of $12.00/hour x 1.5	$18.00
HIGH		
	Basic wage of $15.00/hour x 1.5	$22.50

Hourly System Cost, Including Labor (Low Wage Rate Used)

SYSTEM 1			
	Equipment	$118.80	
	Labor (5)	90.00	
	Total cost/hour		$208.80
SYSTEM 2			
	Equipment	$99.10	
	Labor (4)	72.00	
	Total cost/hour		$171.10
SYSTEM 3			
	Equipment	$107.10	
	Labor (4.5)	81.00	
	Total cost/hour		$188.10
SYSTEM 4			
	Equipment	$145.50	
	Labor (3)	54.00	
	Total cost/hour		$199.50
SYSTEM 5			
	Equipment	$133.80	
	Labor (2)	36.00	
	Total cost/hour		$169.80

System Production Rates

All of the five systems described have approximately the same productivity (number of trees harvested per 8-hour day) on terrain to which they are suited. Each system should operate in the following range:

- High rate = 1,200 stems per 8-hour day during good weather on favorable terrain with easy access and relatively dense stands.
- Median rate = 900 stems per 8-hour day during adverse weather, with less favorable terrain and access, and lighter stand density.
- Low rate = 600 stems per 8-hour day during severe weather on terrain with access or terrain problems, and light stand density.

Cost Delivered to Landing and Loaded

The cost of harvesting and loading can be expressed in dollars per stem, dollars per cubic foot of stemwood, or dollars per ton of stemwood (ovendry-weight basis), as follows:

Cost Per Stem Delivered to Landing and Loaded

System	Production rate		
	High	Medium	Low
	- - - - - *Dollars / stem* - - - - -		
1	1.39	1.86	2.78
2	1.14	1.52	2.28
3	1.25	1.67	2.51
4	1.33	1.77	2.66
5	1.13	1.51	2.26

Cubic-foot Volume of Stemwood Produced Per Hour Related to D.b.h.

Tree d.b.h.	Volume per tree	Volume per hour by production rate		
		High	Medium	Low
	Ft³	- - - - - - - - - *Ft³* - - - - - - - - -		
4	2.2	330	248	165
5	3.5	525	394	263
6	5.5	825	619	413
7	7.5	1,125	844	563
8	11.5	1,725	1,294	863
9	15.0	2,250	1,688	1,125

Cost Per Cubic Foot at Landing, Loaded, by System and Production Rate

Average tree d.b.h.	System number				
	1	2	3	4	5
Inches	*Dollars/ft³ of stemwood*				
	High Production Rate				
4	0.64	0.52	0.57	0.60	0.51
5	.40	.33	.36	.38	.32
6	.25	.21	.23	.24	.21
7	.19	.15	.17	.18	.15
8	.12	.10	.11	.12	.10
9	.09	.08	.08	.09	.08
	Median Production Rate				
4	0.84	0.69	0.76	0.80	0.68
5	.53	.43	.48	.48	.43
6	.34	.28	.30	.32	.27
7	.25	.20	.22	.24	.20
8	.16	.13	.15	.15	.13
9	.12	.10	.11	.12	.10
	Low Production Rate				
4	1.27	1.04	1.14	1.21	1.03
5	.79	.65	.72	.76	.65
6	.51	.41	.46	.48	.41
7	.37	.30	.33	.35	.30
8	.24	.20	.22	.23	.20
9	.19	.15	.17	.18	.15

Average Cost Per Dry Ton of Stemwood ($80\ ft^3$), at Landing, Loaded, Systems 2 and 5, Median Production Level

Average tree diameter	Dollars per dry ton
Inches	
4	$55.20
5	34.40
6	22.40
7	16.00
8	10.40
9	8.00

APPENDIX III: DEVELOPMENT OF THE POLE JOIST AND DATA RELEVANT TO BUILDING CODES

CONTENTS

Tree props, rails, and edge-glued panels are not products that require approval by agencies that administer building codes for successful introduction into the market. Although lodgepole pine studs are subject to building codes, they are so well accepted that a new producer of such studs will have no difficulty with acceptance by code inspectors or the building trades. Similarly, oriented-strand board is now a product recognized and accepted by major building code agencies when manufactured under strict quality control and periodically tested to ensure compliance with the American Plywood Association (1980) performance standards for sheathing and combination subfloor and underlayment.

The fabricated pole joists that are a major product of the proposed operation, however, are new to the marketplace and will require approval by the major code agencies before they can be sold throughout North America. Ultimately, application by the manufacturer should be made to the following code bodies: Building Officials and Code Administrators International; Southern Building Code Congress; and the International Conference of Building Officials.

The balance of this chapter reviews the development of the pole joist and presents a sequence of experimental data supportive of the design values (table 3-3, page 36).

III-1 INCEPTION AND INITIAL TRIALS OF THE CONCEPT

Koch and Burke (1985) conducted an initial experiment in which 16 lodgepole pine joists were fabricated in 16-foot lengths and tested, as follows (fig. III-1):

- Two flange styles, round and half-round.
- Two web materials (lodgepole pine plywood and lodgepole pine flakeboard).
- Four replications (an equal number of flanges for these replications were cut from each of two Montana locations (3,750 feet elevation near Seeley Lake, and 4,500 feet near Superior).

The plywood for webs was three-ply C-DX sheathing made from 1/8-inch lodgepole veneers rotary-peeled and fabricated in Bonner, MT. When glued, the plywood had an average density of 29.9 lb/ft^3 based on ovendry weight and volume. Actual plywood thickness, measured at test, averaged 0.380 inch.

The flakeboard for webs was manufactured at the Seimpelkamp plant in West Germany from lodgepole pine shipped green from the Bitterroot Valley in Montana. The flakeboard was nominally three-eighths inch thick, with random orientation of flakes. Face flakes were 0.018 inch thick and 3 inches long; core flakes were 0.023 inch thick and 1.5 inches long. The panels were bonded with phenol-formaldehyde resin and hot-pressed to an

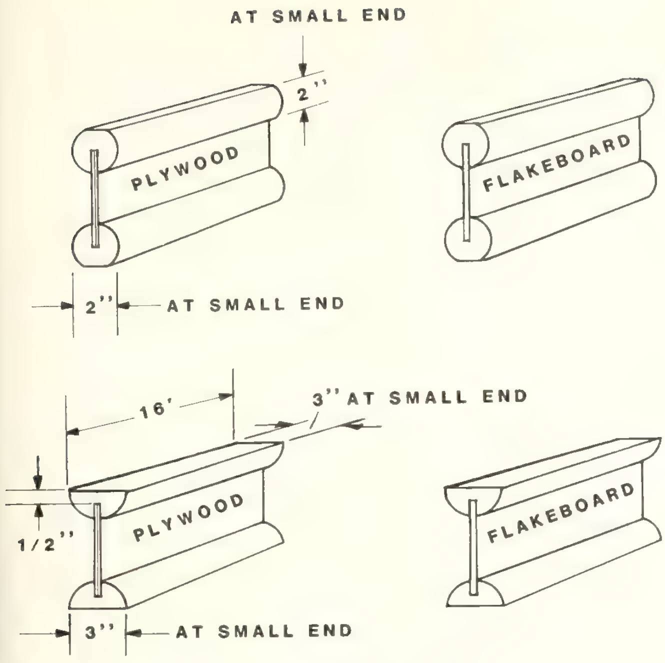

Figure III-1—Fabricated lodgepole pine joists in the initial experiment (Koch and Burke 1985) utilized both round and half-round flanges. Later experiments resulted in abandonment of the half-round flanges and concentration on round or semiround flanges.

average density of 46 lb/ft^3, based on ovendry weight and volume. Actual thickness, measured at test, averaged 0.398 inch.

Lodgepole pine trees for flanges were selected to be straight—usually with less than 2 inches sweep in the 17-foot length of interest. For the round flanges, required small-end diameter was 2 inches plus one-fourth inch minus 0; large-end diameters varied from 2.48 to 3.56 inches. The round flanges were unmachined except for grooving on one side to receive the web and slight flattening on the opposite side to provide a nailing surface.

As originally conceived and tested in the factorial experiment just outlined, two designs were described. The first of these designs utilized rounds for flanges, while the second used half-rounds (fig. III-1). For a variety of reasons explained in Burke and Koch (1987), the second design was dropped in favor of the first. Subsequent discussion and data relate, therefore, only to fabricated joists with round (or semiround) flanges.

Moisture contents at test and specific gravities (based on ovendry weight and volume) of the joist components were as follows:

Item	Moisture content	Specific gravity
	Percent	
Flanges		
in joists with plywood webs	10.0	0.46
in joists with flakeboard webs	10.1	.44
Plywood webs	8.1	.48
Flakeboard webs	7.9	.74

When tested to failure in flexure over a 15-foot span with load applied at two points 40 inches apart and symmetrical about the midlength of the joist, the two types of 9.5-inch-deep joists carried loads as follows (derived from table III-1):

Statistic	Web type: Plywood	Web type: Flakeboard
Load at failure, pounds		
Average	4,076	5,140
Standard deviation	308	372
95 percent exclusion limit	3,250	4,143
95 percent exclusion limit/2.1	1,548	1,973
Design resistive moment, foot-pounds	4,515	5,755

The values in the two foregoing columns do not differ statistically. The 95 percent exclusion limit was calculated to allow 75 percent probability that at least 95 percent of the strengths (loads at failure) from which the samples were drawn will exceed the values tabulated.

Failures were mostly in the flanges, and were about evenly divided between compression and tension failures (table III-1). It was easier to attain a good web-flange joint with the flakeboard than with the plywood. None of the failures in the joist occurred at joist midlength where a web butt joint was located (the web sections were 8 feet long).

Because of stem taper and irregularities in the lodgepole pine flanges, section modulus varied along the length of each joist. For this reason, and because the mechanical properties of the minimally machined flange material were unknown, section transformations to compute modulus of rupture and modulus of elasticity were not attempted—but stiffness (EI) was evaluated.

The two types of 9.5-inch-deep joists had deflection characteristics as follows (derived from table III-1):

Statistic	Web type: Plywood	Web type: Flakeboard
Deflection per 100-pound load increment, inch		
Average	0.063	0.048
Standard deviation	.005	.003
Average EI, that is, modulus of elasticity x moment of inertia, million inch^2 pounds	179.6	235.8

III-2 WEB MATERIAL—PLYWOOD VS. ORIENTED-STRAND BOARD

The differences tabulated, while not statistically significant—probably because of the few joists tested, suggest that flakeboard webs may yield stronger and stiffer joists than plywood webs of the same thickness and species. There are pros and cons for both materials, however. Additionally, while a three-ply plywood web is moderately uniform in properties, flakeboard properties can vary widely, depending on flake geometry, flake orientation, and board specific gravity and resin content.

In a general sense, plywood is lighter than flakeboard (about 30 lb/ft^3 compared to 40 pounds or more for flakeboard, ovendry-weight basis). Also, plywood is more stable

Table III-1—Maximum load at failure, load at elastic limit, and deflection characteristics of 9.5-inch-deep pole joists with plywood and flakeboard webs. See text for dimensions of flanges and webs. Top and bottom of joists were flattened slightly to provide a nailing surface (Koch and Burke 1985)

Replication, average, standard deviation	Maximum load at failure	Deflection at failure	Load at elastic limit	Deflection per 100-pound load	Failure mode
	Pounds	*Inches*	*Pounds*	*Inch*	
		Plywood webs			
1	4,015	2.54	3,400	0.060	Tension
2	3,780	2.35	3,700	.060	Tension
3	4,510	2.89	3,800	.060	Tension
4	4,000	2.81	3,900	.070	Compression
Average	4,076	2.65	3,700	.063	
Std. dev.	308	.25	216	.005	
		Flakeboard webs			
1	4,760	2.11	4,760	0.044	Tension
2	5,650	2.67	3,800	.047	Compression
3	5,100	2.65	4,300	.051	Compression-tension
4	5,050	2.44	4,200	.048	Compression
Average	5,140	2.47	4,265	.048	
Std. dev.	372	.26	394	.003	

(that is, creeps less) under inplane loads than flakeboard, and has significantly less thickness swell when wetted than flakeboard.

Importantly, however, flakeboard has greater inplane strength and stiffness than plywood. Also, our early experience with the German-made lodgepole pine flakeboard described in the foregoing section indicated that it was easier to get a good glue bond between web and flange with flakeboard than with plywood.

Strength and stiffness of flakeboard are both positively correlated with density of the board; that is, dense flakeboards are stiffer and stronger than less-dense flakeboards. This relationship must be utilized with judgment, however, as joists must be kept as lightweight as possible while retaining required strength and stiffness.

When used as a joist web, flakeboard with random flake orientation exceeds oriented-strand board in both inplane strength and stiffness.

Experimental data are insufficient to determine whether continuous webs are superior to webs comprised of discrete short sections 4 to 8 feet in length.

In summary, it appears that maximum inplane strength and stiffness are to be obtained with flakeboard webs having random flake orientation, but such webs will be heavier, and will swell more in thickness and perhaps have more inplane creep than plywood of the same thickness. Because the integrity of the joint between web and flange must be consistently good to maintain uniform joist strength, surface flakes must be tightly bonded to core flakes to prevent shear failures at web surfaces. Tests of joint strength showed no clear difference in webs of oriented-strand board compared to flakeboard with randomly oriented flakes. On the basis of all these considerations, it was decided that the webs should be of flakeboard, with random flake orientation.

For a comparison of flexural properties of joists with flakeboard and plywood webs subjected to various environmental conditions, see Chen and others (1989).

III-3 STEM DIAMETER VS. COMPRESSION MECHANICAL PROPERTIES

The literature on mechanical properties of unmachined stem sections of very small lodgepole pine trees is sparse. To supply needed data for development of the pole joists, seven small lodgepole pines were cut in the Lubrecht Experimental Forest (about 47 degrees latitude), transported to the University of Montana campus in Missoula, hand peeled with a dull spud, measured, and crosscut to yield 21 compression specimens 6 inches long, each containing a knot cluster—seven each (one from each tree) of diameters 1, 2, and 3 inches. After air drying for 2 months the unmachined specimens were destructively tested in compression parallel to the grain, with results—adjusted to a specimen moisture content of 10 percent of ovendry weight—summarized from Burke and Koch (1986) and figures III-2, III-3, III-4, and III-5 as follows:

Specimen diameter	Modulus of elasticity	Maximum crushing strength	Proportional limit
Inches	*M lb/in²*	*Lb/in²*	*Lb/in²*
1	1,322	4,850	3,090
2	1,262	5,590	3,760
3	1,728	5,860	3,870

With a couple of exceptions, these values were not significantly different. Where significant differences were observed, results suggested that the 3-inch-diameter sections had superior mechanical properties.

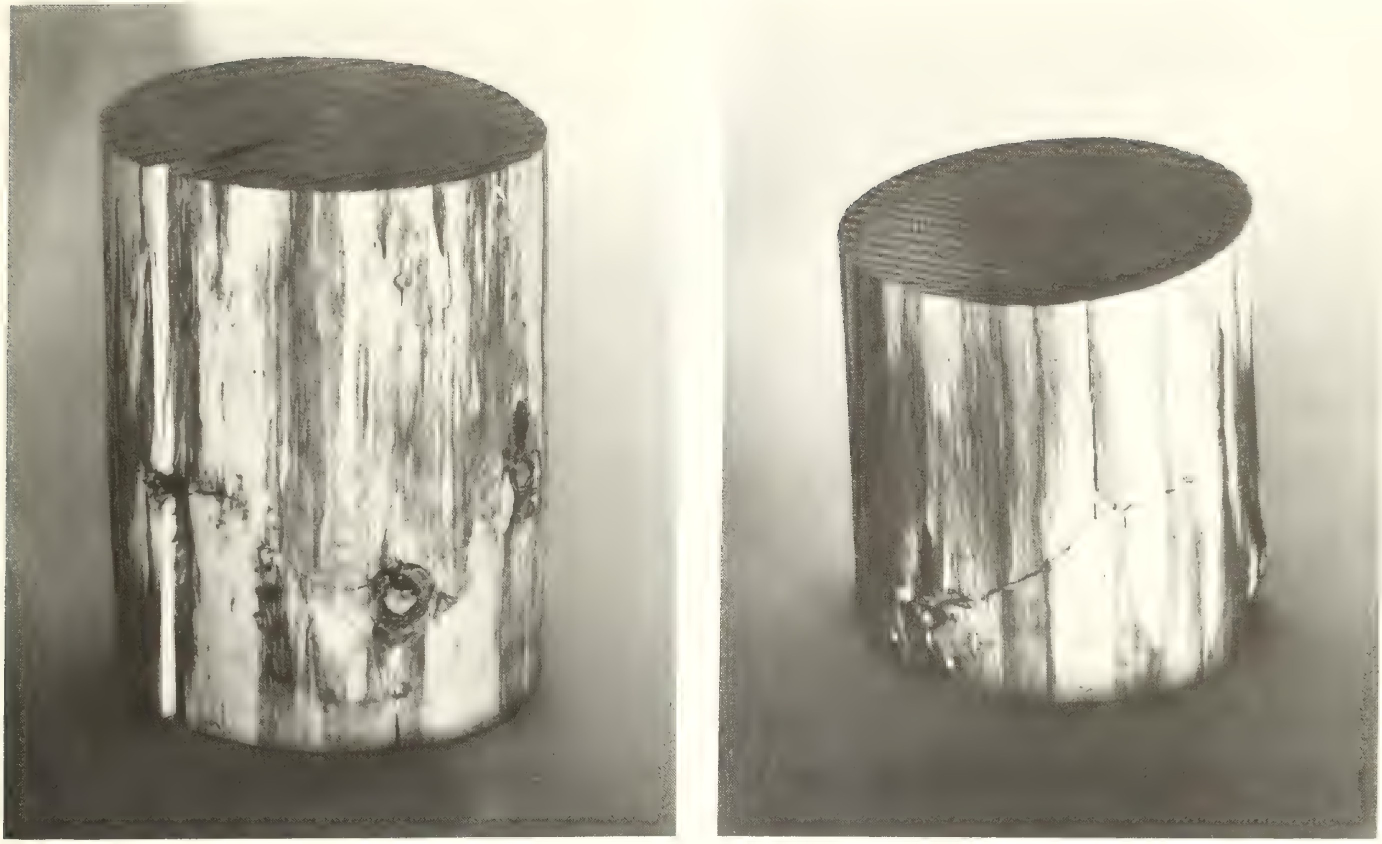

Figure III-2—Typical spiral compression failures passing through knots and knot clusters. Drying checks did not appreciably alter the spiral form of failures. The specimens illustrated are 4 inches in diameter. (From Burke and Koch 1986.)

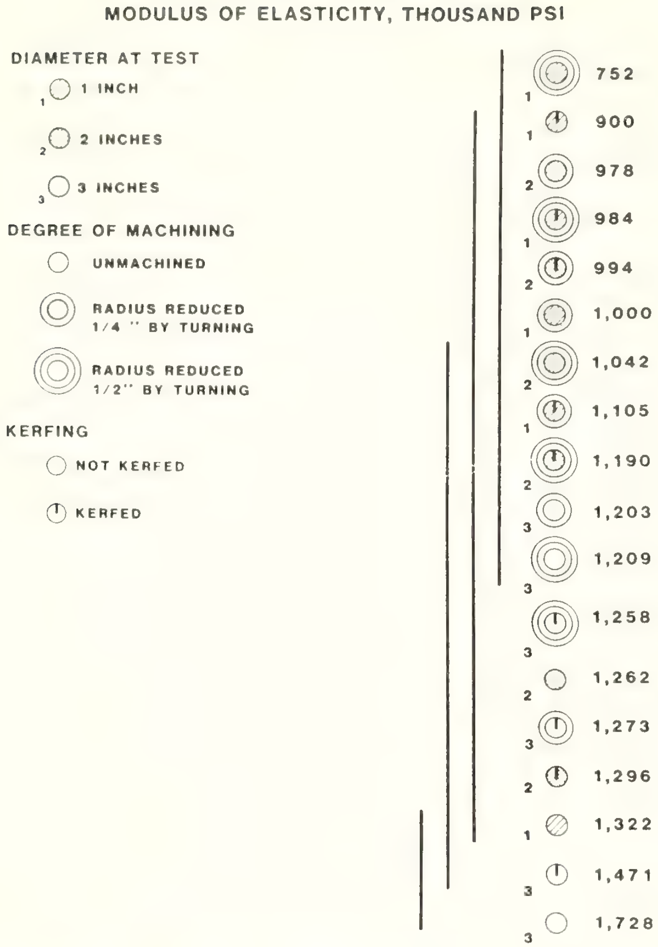

Figure III-3—Specimens from doweling-effects experiment (with key) arrayed according to modulus of elasticity measured in compression parallel to the grain. Values spanned by a single line do not differ significantly at the 0.05 level. (From Burke and Koch 1986.)

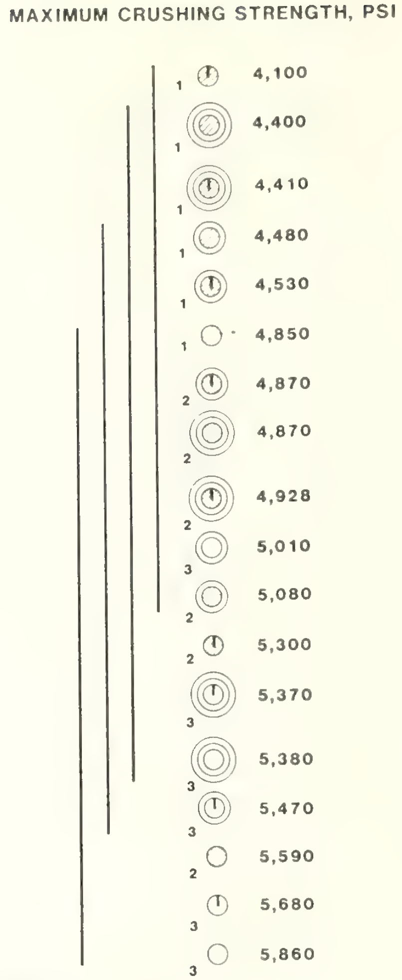

Figure III-4—Specimens from doweling-effects experiment arrayed according to maximum crushing strength parallel to the grain. Values spanned by a single line do not differ significantly at the 0.05 level. See figure III-3 for key. (From Burke and Koch 1986.)

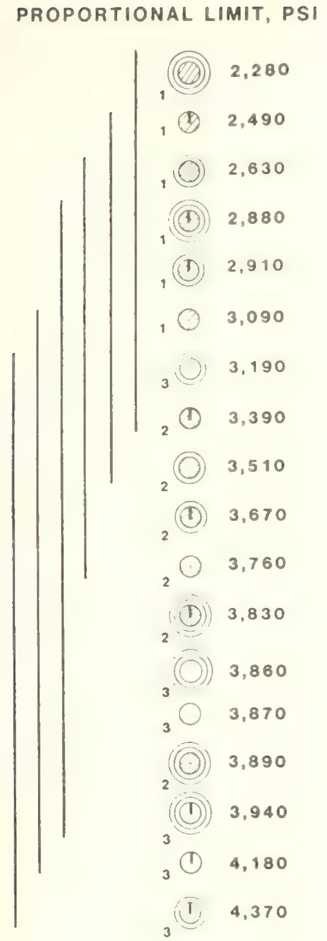

Figure III-5—Specimens from the doweling-effects experiment (same as in figure 10-3) arrayed according to proportional limit in compression parallel to the grain. Values spanned by a single line do not differ significantly at the 0.05 level. See figure III-3 for key. (From Burke and Koch 1986.)

In these compression tests, failures were typically spiral in form, initiated at knots, and progressed from one knot to another (fig. III-2). Some shelling along growth rings was noted.

For lodgepole pine these specimens had fairly wide growth rings; they averaged 14.2 rings per inch. Specific gravity averaged about 0.46 based on ovendry volume and ovendry weight.

III-4 EFFECT OF DOWELING AND KERFING ON MECHANICAL PROPERTIES UNDER COMPRESSION

For uniformity of pole joists in manufacture and use, it seems necessary to reduce tapered stem sections for flanges to uniformly sized dowels; the amount of wood removed during the doweling operation will vary from stem section top to butt, but will frequently be in the range from 0.25- to 0.50-inch radius. Additionally, the dowels must be kerfed (dadoed) to receive the webs. In an effort to assess the effect of such doweling and kerfing on flange mechanical properties, Burke and Koch (1986) matched the specimens described in the previous tabulation with specimens from the same trees kerfed and with either 0.25- or 0.50-inch of radius removed during doweling to achieve machined diameters of 1, 2, and 3 inches. The kerfs (0.125 inch wide, radial to pith) were machined in the dowels while they were still green, and then the specimens were air dried for 2 months. Results of destructive tests in compression parallel to the grain, with values adjusted to a specimen moisture content of 10 percent of ovendry weight, are summarized as follows:

Specimen diameter (inches) and property	Unmachined	Kerfed and doweled, 1/4-inch radius removed	Kerfed and doweled, 1/2-inch radius removed
1 inch			
Modulus of elasticity, M lb/in^2	1,322	1,105	984
Maximum crushing strength, lb/in^2	4,850	4,530	4,410
Proportional limit, lb/in^2	3,090	2,910	2,880
2 inches			
Modulus of elasticity, M lb/in^2	1,262	994	1,190
Maximum crushing strength, lb/in^2	5,590	4,870	4,928
Proportional limit, lb/in^2	3,760	3,670	3,830
3 inches			
Modulus of elasticity, M lb/in^2	1,728	1,273	1,258
Maximum crushing strength, lb/in^2	5,860	5,470	5,370
Proportional limit, lb/in^2	3,870	4,370	3,940

These data suggest that doweling and kerfing have minor effect on proportional limit, but reduce maximum crushing strength by about 10 percent and modulus of elasticity by about 20 percent.

As noted previously, unmachined specimens averaged 14.2 rings per inch. Those with 0.25-inch radius removed averaged 12.0 rings per inch, and those with 0.50-inch radius removed averaged 10.7 rings per inch.

The average maximum crushing stress parallel to the grain of these 42 doweled specimens from Lubrecht Experimental Forest was about equal to the average ultimate tensile stress of eighty-one 2.25-inch-diameter lodgepole pine dowels sampled from throughout the major range of variety *latifolia* (see table III-3).

To confirm the general observations tabulated above, another group of samples were taken at breast height from a stand of lodgepole pine at 3,500 feet elevation located on

a flat between the south end of Hungry Horse Reservoir and Spotted Bear Ranger Station in northwestern Montana (at about 48.5 degrees latitude). Again 6-inch-long compression specimens were prepared: seven were 2 inches in diameter and unmachined (37.6 rings per inch and specific gravity of 0.53 based on ovendry volume and ovendry weight); another seven measured 2 inches in diameter after kerfing to the pith and removal of 0.50 inch in radius during doweling (24.9 rings per inch and specific gravity of 0.49 based on ovendry volume and ovendry weight). Mechanical properties of these compression specimens at 10 percent moisture content were reported by Burke and Koch (1986) as follows:

Property	Unmachined	Kerfed and doweled, 1/2-inch radius removed
Modulus of elasticity, M lb/in^2	1,848	1,410
Maximum crushing strength, lb/in^2	7,738	7,156
Proportional limit, lb/in^2	5,484	4,472

These values for 2-inch-diameter specimens suggest that kerfing and removal of 0.50-inch radius during doweling reduce modulus of elasticity about 24 percent, maximum crushing strength about 8 percent, and proportional limit about 18 percent.

In summary, it is probable that in the range of diameters contemplated for pole joist flanges, kerfing and doweling reduce modulus of elasticity 20 to 30 percent and reduce maximum crushing stress and proportional limit by about 10 percent. Study of figures III-3, III-4, and III-5, and of Burke and Koch (1986, part III) suggests that doweling alone (without kerfing) reduces these mechanical properties by about the same percentages. Kerfing alone (without doweling), however, causes only about half the percentage reductions noted above.

III-5 EXPLORATORY STUDY OF VARIATION IN JOIST PROPERTIES WITH CHANGES IN FLANGE DIAMETER AND JOIST DEPTH

The objective of the experiments described in this section (Burke and Koch 1985) was fabrication and test of joists 9.5, 11.875, 14, and 16 inches deep with doweled flanges in a range of diameters. Webs were locally procured lodgepole pine oriented-strand board—three-eighths inch thick for the joists 9.5 and 11.875 inches deep, and seven-sixteenths inch thick for the joists 14 and 16 inches deep. All flanges had a 1.5-inch-wide flat planed on one side, and a rectangular dado on the opposite side to receive the web—three-fourths inch deep for the joists 9.5 and 11.875 inches deep, seven-eighths inch deep for the 14-inch joists, and 1 inch deep for the 16-inch joist (fig. III-6). The oriented-strand board had relatively low density—about 39.9 lb/ft^3 at a moisture content of about 6 percent of ovendry weight.

The joists were fabricated 26 feet long with a 12/1 glued splice at center length of each flange. Web sections were 4 feet long, but arranged so that one of the web butt joints (one-eighth inch space between web sections) was located at midlength.

Each depth of joist was made with a range of flange diameters (2-inch minimum green diameter and 3.5-inch maximum green diameter) (table III-2). Dowels were dry at time of fabrication so the actual flange diameters were slightly smaller than the nominal green diameters—about 0.10 inch smaller for dowels measuring 2.25 inches when green, and 0.125 inch smaller for dowels measuring 3.0 inches when green.

The joists were loaded to failure, with 24 feet between supports in edgewise-flexure, on a 60,000-pound testing machine equipped with lateral supports to preclude joist buckling. The load was applied at two points 60 inches apart and symmetrical about the midlength of the joist.

The purpose of these essentially unreplicated tests was to gain some empirical data on the relationship between flange diameter, joist depth, and the mechanical properties of EI (modulus of elasticity x moment of inertia—a measure of stiffness), and resistive moment at failure (a function of maximum load).

Data in table III-2 suggested that with the flange shape depicted in figure III-6, target values from table 3-3 could be obtained with dowels turned green to 2.25 inches in diameter for the 9.5-inch joists and 2.5 inches for the 11.875-inch joists.

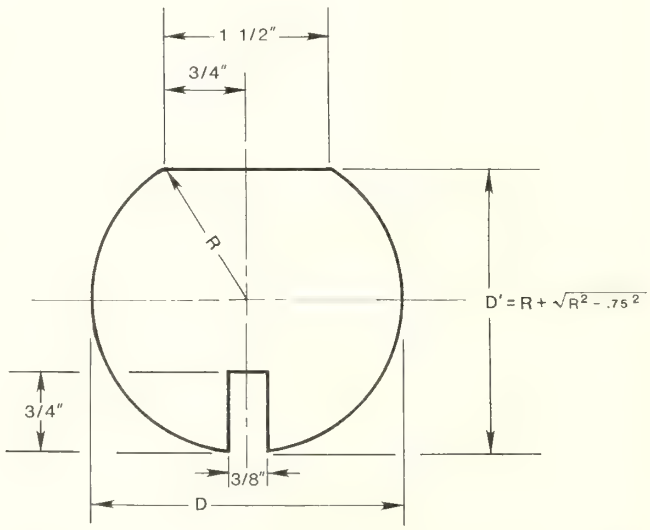

Figure III-6—Diagram of dowel flanges for joists 9.5 and 11.875 inches deep in exploratory tests of joists given 2-point loading over a 24-foot span.

Table III-2--EI and maximum resistive moments (adjusted to moisture content of 10 percent of ovendry weight) of joists 9.5, 11.875, 14, and 16 inches deep with lodgepole pine dowel flanges of various diameters and flakeboard webs

Flange diameter (green)	Number of specimens	At test weight per lineal foot	EI	Maximum load	Maximum resistive moment
Inches		*Pounds*	*Million inch² pounds*	*Pounds*	*Foot pounds*
		9.5-inch-deep joist, 3/8-inch web with 3/4-inch groove depth			
2.0	1	1.8	190	2,600	12,350
2.5	2	2.4	242	3,025	14,368
3.0	1	3.2	322	2,500	11,875
3.5	1	3.5	442	2,900	13,755
		11.875-inch-deep joist, 3/8-inch web with 3/4-inch groove depth			
2.0	1	2.2	265	2,910	13,822
2.5	1	2.4	347	2,455	11,661
		14-inch-deep joist, 7/16-inch web with 7/8-inch groove depth			
2.5	1	3.2	575	4,100	19,475
3.0	2	4.0	754	5,250	24,937
3.5	2	4.9	896	4,350	20,662
		16-inch-deep joist, 7/16-inch web with 1-inch groove depth			
3.0	1	4.3	1,180	4,975	23,631
3.5	1	5.3	1,296	4,400	20,900

Table III-3—Three mechanical properties of *latifolia* stemwood sections extending from 10 to 20 percent of tree height, and equilibrated to 12 percent moisture content—related to latitude (Pellerin and others in preparation)

Latitude	Dynamic MOE[1]	Static MOE[1]	Ultimate tensile stress[2]
Degrees	- - - - *Million lb/in²* - - - -		*Lb/in²*
40	1.427	1.163	4,120
42.5	1.203	.805	4,060
45	1.233	1.280	4,770
47.5	1.172	.906	4,970
50	1.891	1.519	6,720
52.5	1.754	1.796	5,650
55	1.630	1.565	5,730
57.5	1.366	1.189	4,720
60	1.725	1.455	5,680
Average	1.489	1.298	5,158

[1]Determined in unmachined stem sections.
[2]Determined from stem sections necked down to 2.25 inches in diameter, including knots present.

III-6 GEOGRAPHIC VARIATION OF SPECIFIC GRAVITY AND MECHANICAL PROPERTIES OF LODGEPOLE PINE STEMWOOD

In North America the range of lodgepole pine extends from below 40 degrees latitude to north of 60 degrees latitude, and across more than 10 degrees of longitude at each latitude—mostly centered on the Rocky Mountains (figs. 2-2 and III-7). With such a broad distribution it is not surprising that specific gravity, and therefore mechanical properties, of stemwood of the species varies with geographic location. The discussion that follows is concentrated on three aspects of this variation: (1) the variation in specific gravity of stemwood of lodgepole pine varieties *latifolia* and *murrayana*, the varieties of primary importance to this analysis; (2) the variation in modulus of elasticity and tensile strength of stemwood sections from trees 3 inches in d.b.h. over the North American range of the varieties; and (3) the variations observed in the United States only in mechanical properties of unmachined stemwood sections of lodgepole pine in compression parallel to the grain.

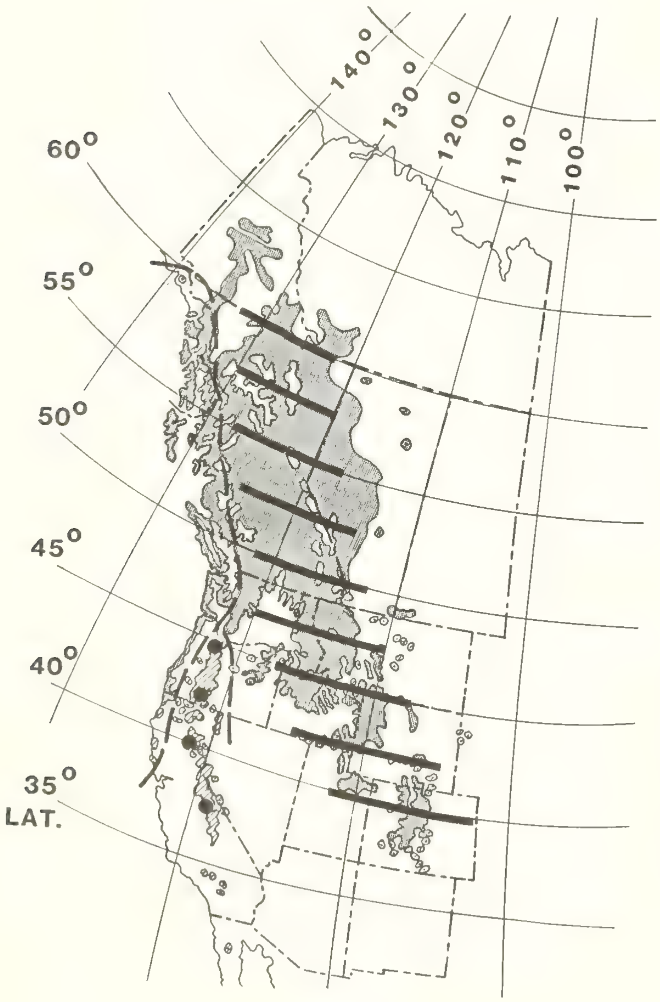

Figure III-7—Sampling zones superimposed on Little's (1971) range map of lodgepole pine in North America. Variety *latifolia* is mapped to the right of the dashed lines, *murrayana* between them, and *contorta* to the left of them. Variety *contorta* was not studied because of its small potential for commercial use.

Locating and Selecting the 243 *Latifolia* Trees in North America

The sample area spanned from 40 to 60 degrees (inclusive) at 2.5-degree intervals; the width of the sample area was 10 degrees of longitude, with sample area shifting 2.5 degrees west for each 2.5 degrees shift north in latitude (fig. III-7). Sample band width was 0.5 degree of latitude on each side of the nominal latitude line; for example, each latitude band was 1 degree deep in the north-south direction (60 nautical miles), and 10 degrees of longitude wide in the east-west direction.

Within each of these nine latitudinal sampling bands, natural unthinned stands were identified with the following constraints: adjacent to road traversable by pickup truck; within boundaries of National or Provincial Forests; and containing some more-or-less level benches or flats.

It was found that at least nine such stands could be identified within each sampling band. The identified stands were ranked by elevation, and then the three highest, the three most intermediate, and the three lowest were selected for sampling. These elevational zones were highest in the south and lowest in the north; elevational zone width was broadest at midlatitude (fig. III-8).

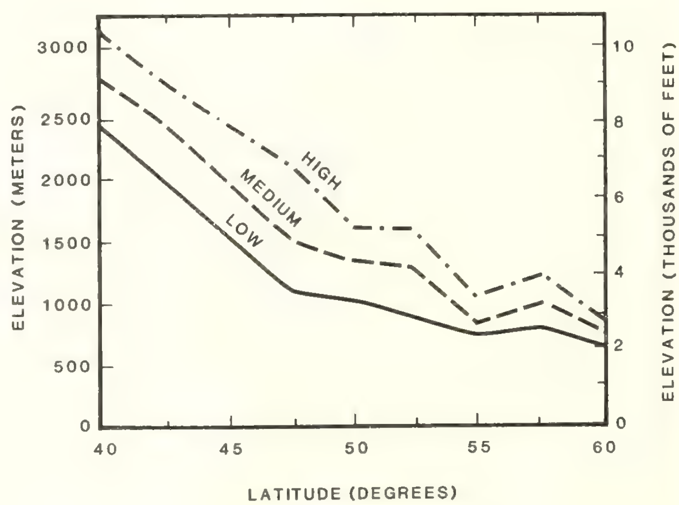

Figure III-8—Elevational trends in the three zones (low, medium, and high) where lodgepole pine (var. *latifolia*) was sampled along nine latitudes. Each plotted point is the average for nine trees; that is, three diameters by three replications (Koch 1987, p. 6).

On a bench or flat typical of each of these selected stands, single trees 3 inches, 6 inches, and 9 inches in d.b.h. and free of insects and diseases were taken that, in the collector's view, typified within-stand trees of these diameters on that bench or flat. Thus, 27 *latifolia* trees were taken from each of the nine latitudes—3 diameters x 3 elevations x 3 replications, for a total of 243 trees.

It is important to note that this sampling scheme resulted in selection of 3-, 6-, and 9-inch trees that were of approximately the same age because most of the stands were of fire origin. Thus, most of the small-diameter trees were suppressed, while the larger trees were the fast growers.

For a complete description of the field and laboratory work see Koch (1987, p. 9).

Locating and Selecting the 36 *Murrayana* Trees in North America

The sample areas extended from 37½ to 45 degrees latitude at 2.5-degree intervals; for example, trees were sampled at 37½, 40, 42½, and 45 degrees—but only at one longitude per latitude (fig. III-7).

The same three constraints on location applied to *latifolia* also applied to *murrayana*, but *murrayana* was sampled only from midelevation, as follows:

Latitude	**Elevation**
Degrees	*Feet*
37½	7,880
40	5,499
42½	6,581
45	3,766

Thus, nine *murrayana* trees were taken from each of the four latitudes—3 diameters x 1 elevation x 3 replications, for a total of 36 trees.

For a complete description of the field and laboratory work see Koch (1987, p. 9).

Specific Gravity (North America)

Latifolia—With all data pooled, stemwood (from 6-inch high-stump to apical tip) specific gravity based on ovendry weight and green volume averaged 0.418, with standard deviation of 0.032. It was unrelated to elevational zone, but negatively correlated with d.b.h. as follows (fig. III-9):

D.b.h.	**Average specific gravity**	**Standard deviation**
Inches		
3	0.427	0.037
6	.419	.028
9	.407	.026

Stemwood specific gravity was positively correlated with latitude so that specific gravity increased with increased latitude to the Canadian border and then was more-or-less constant but with some diminution at extreme northern latitudes (fig. III-9) as follows:

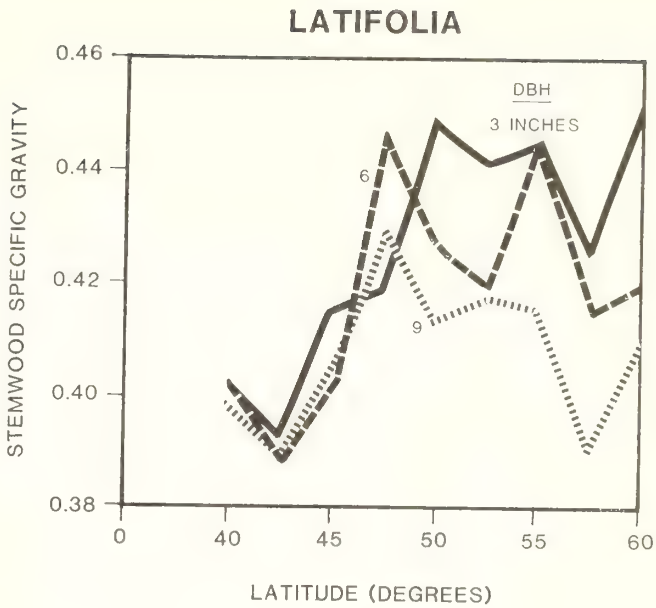

Figure III-9—Specific gravity of stemwood (6-inch stump height to apical tip), based on ovendry weight and green volume, of *latifolia* trees of three diameters related to latitude (Koch 1987, p. 178).

Latitude	**Specific gravity**
Degrees	
40	0.401
42.5	.390
45	.408
47.5	.431
50	.430
52.5	.426
55	.435
57.5	.410
60	.427

Average specific gravity (basis of ovendry weight and green volume) of entire stemwood from 6-inch stump height to apical tip in *latifolia* trees of the diameters studied can be closely estimated from the specific gravity of a complete stemwood disk taken at 20 percent of tree height, by the following relationship (R^2 = 0.878; standard error of estimate = 0.011):

Average stemwood specific gravity = 0.07524 + 0.82479 (stemwood specific gravity at 20 percent of tree height)

Stemwood specific gravity diminishes curvilinearly from stump top to near the base of the live crown, above which it remains more-or-less constant—or increases slightly (fig. III-10). Variation patterns were similar for the three tree diameters studied, but the level of the curves varied significantly with diameter—that is, at all heights small-diameter trees had higher stemwood specific gravity than large trees. At 60 percent of tree height, that is, just above the base of the live crown, stemwood

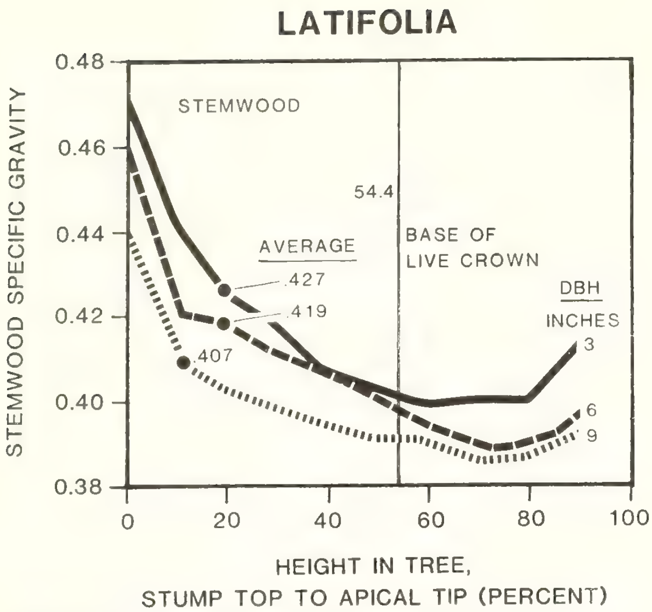

Figure III-10—Specific gravity of stemwood (based on ovendry weight and green volume) of *latifolia* trees of three diameters related to height in tree and base of live crown (Koch 1987, p. 180).

specific gravity differed little with diameter, however, averaging 0.399, 0.395, and 0.391 for trees 3, 6, and 9 inches in diameter.

With diameter data pooled, stemwood specific gravity relationships to height in tree also differed significantly with latitude (fig. III-11).

Murrayana—Average entire stemwood specific gravity was inversely correlated with average growth-ring width at 6-inch stump height ($R^2 = -0.490$); that is, fast-growing trees had lower specific gravity than slow growers.

Average specific gravity (based on ovendry weight and green volume) of entire stemwood from 6-inch-high stump top to apical tip in *murrayana* trees can be closely estimated from specific gravity of a stemwood disk taken at 20 percent of tree height (figs. III-12 and III-13) by the following relationship ($R^2 = 0.937$; standard error of the estimate = 0.012):

Average stemwood specific gravity = 0.0917 + 0.8014 (stemwood specific gravity at 20 percent of tree height)

For trees 6 and 9 inches in d.b.h., average stemwood specific gravity was least in the southernmost latitude.

Average stemwood specific gravity was inversely correlated with d.b.h., as follows:

D.b.h.	Average specific gravity	Standard deviation
Inches		
3	0.482	0.039
6	.440	.042
9	.407	.031

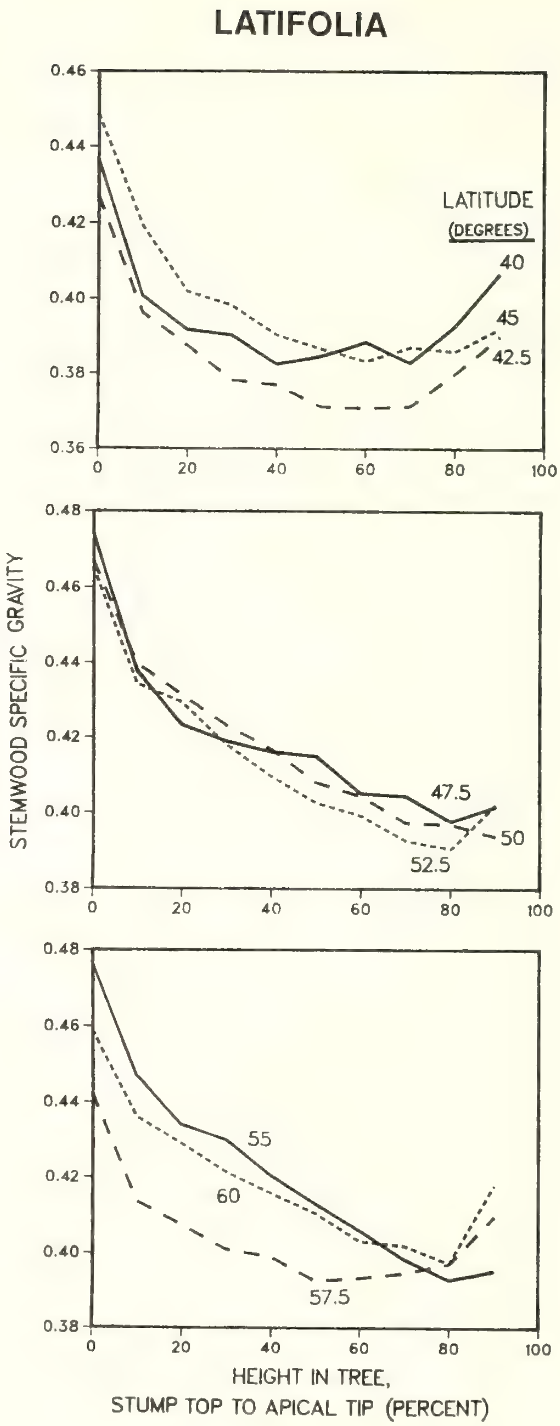

Figure III-11—Stemwood specific gravity (based on ovendry weight and green volume) of *latifolia* trees related to height in tree and latitude (Koch 1987, p. 181).

In *murrayana* trees, stemwood specific gravity curvilinearly diminishes above stump height to near the base of the live crown (figs. III-12 and III-13). At all percentages of tree height below 90 percent, stemwood specific gravity is negatively correlated with tree d.b.h. (fig. 10-12). Stemwood specific gravity at 20 percent of tree height approximates stemwood average specific gravity (fig. III-13).

Comparison of *Latifolia* With *Murrayana*—Specific gravity of entire stemwood of *murrayana* was found to be greater than that of *latifolia* at the three latitudes sampled in common (40, 42.5, and 45 degrees—in midelevational zones), as follows:

D.b.h.	*Latifolia*	*Murrayana*
Inches		
3	0.409	0.482
6	.396	.454
9	.396	.412
Average	.395	.441

With diameter data pooled from the three latitudes common to the two varieties, the difference was observable at all percentages of tree heights (fig. III-14).

In more northerly latitudes, *latifolia* stemwood has higher specific gravity than the values tabulated above (fig. III-9).

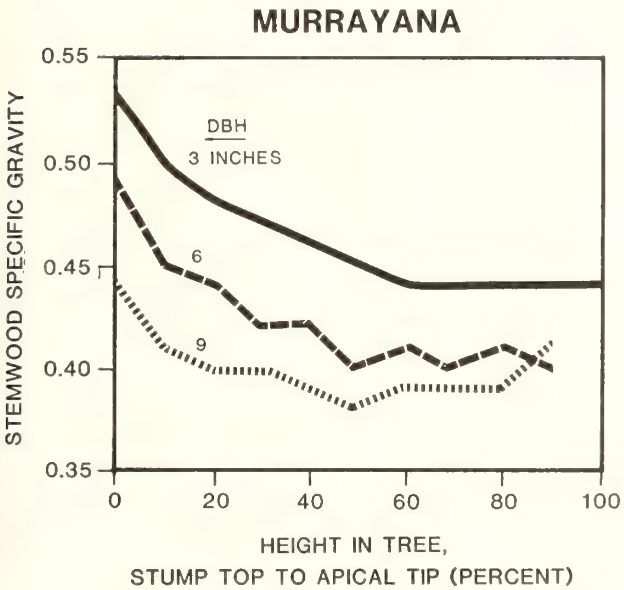

Figure III-12—Stemwood specific gravity (based on ovendry weight and green volume) for *murrayana* trees of three diameters, related to height in tree (Koch 1987, p. 228).

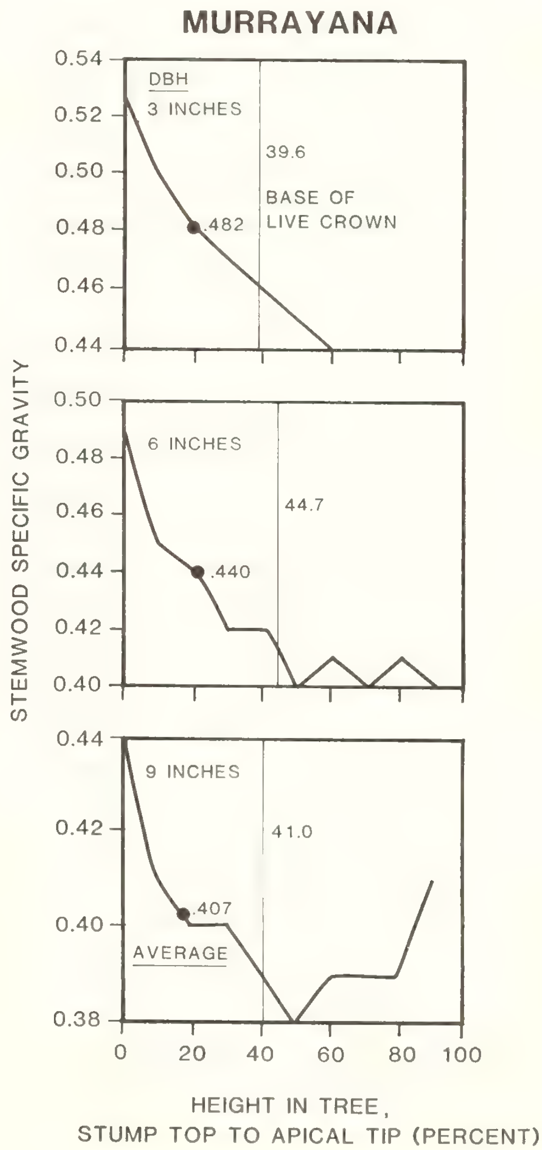

Figure III-13—Stemwood specific gravity (based on ovendry weight and green volume) for *murrayana* trees of three diameters, related to height in tree, position of crown base, and position and value of stem-average stemwood specific gravity (Koch 1987, p. 228).

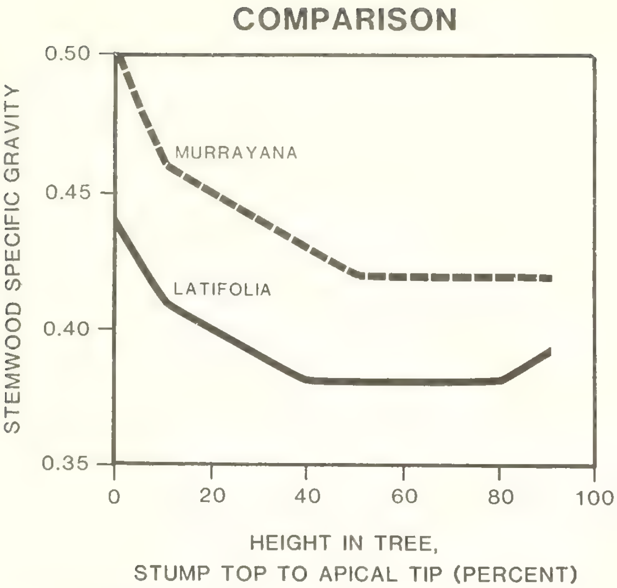

Figure III-14—Specific gravity of stemwood, ovendry weight and green volume basis; *latifolia* compared to *murrayana* at latitudes 40, 42.5, and 45 degrees in midelevation zones, as related to height in tree (Koch 1987, p. 242).

Modulus of Elasticity of Unmachined Stemwood Sections (North America)[1]

From the trees 3 inches in d.b.h. collected in North America as just described (fig. III-7), stemwood sections between 10 and 20 percent of tree height were removed for evaluation in compression and tension. Evaluated, therefore, were stem sections from 81 *latifolia* and 12 *murrayana* trees.

Data from *Latifolia* and *Murrayana* Pooled—The stem sections, unmachined and equilibrated to 12 percent moisture content, were nondestructively evaluated for static modulus of elasticity (MOE) in compression parallel to the grain, and dynamic MOE computed from stress wave propagation times. Specific gravity of the stem sections (based on ovendry weight and volume at 12 percent moisture content) was also determined. Relationships between these properties were as follows (MOE in million lb/in^2):

$$\text{Specific gravity} = 0.50352858 + 0.03149713 \,(\text{dynamic MOE}) \qquad R = 0.2502$$

$$\text{Specific gravity} = 0.52331942 + 0.02033634 \,(\text{static MOE}) \qquad R = 0.2154$$

$$\text{Static MOE} = 0.17581132 + 0.74253811 \,(\text{dynamic MOE}) \qquad R = 0.5565$$

***Latifolia* vs. *Murrayana* Modulus of Elasticity**—Sampling latitudes in common for the two varieties were 40, 42$^1/_2$, and 45 degrees (fig. III-7) at medium elevation. Within these common sampling zones, only at 40 degrees did the two differ significantly, and then only in dynamic MOE; *latifolia* had significantly higher dynamic MOE (1.420 million lb/in^2) than *murrayana* (0.837 million lb/in^2).

For *murrayana*, dynamic MOE was positively correlated with latitude, with values at 45 degrees (1.303) and 42.5 degrees (1.174) significantly greater than at 37.5 degrees (0.665); the value at 40 degrees did not differ significantly from values at the other three latitudes.

Latifolia—While a general positive correlation with mechanical properties and latitude was discernible, anomalies in the data from 40 and 47$^1/_2$ degrees latitude made statistical interpretation of the data difficult (table III-3).

Static MOE at 52.5 degrees (1.796) was significantly greater than at 45 degrees (1.280), 57.5 degrees (1.189), 40 degrees (1.163), 47.5 degrees (0.906), and 42.5 degrees (0.805). Static MOE was significantly less at 47.5 and 42.5 degrees than at the other latitudes.

Ultimate Tensile Strength of Doweled Stemwood (North America)[1]

Following nondestructive static and dynamic modulus of elasticity evaluations of the unmachined stem sections, they were turned to 2.25 inches in diameter and tested to destruction in tension.

***Latifolia* and *Murrayana* Data Pooled**—Relationships between the modulus of elasticity values and specific gravities of the unmachined sections, and the ultimate tensile stress of the 2.25 inch dowels machined from the stem sections were as follows:

$$\text{Ultimate tensile stress} = 3308.82333 + 1448.31302 \,(\text{static MOE}) \qquad R = 0.4910$$

$$\text{Ultimate tensile stress} = 2152.90980 + 2065.23983 \,(\text{dynamic MOE}) \qquad R = 0.5248$$

$$\text{Ultimate tensile stress} = -361.68961 + 9951.77743 \,(\text{spec. grav.}) \qquad R = 0.3184$$

In the foregoing equations, ultimate tensile stress is in lb/in^2, modulus of elasticity is in million lb/in^2, and specific gravity is based on ovendry weight and volume at 12 percent moisture content.

***Latifolia* vs. *Murrayana* Ultimate Tensile Strength**—Ultimate tensile stress did not differ significantly between the two varieties—a somewhat surprising result in view of the higher specific gravity of *murrayana* at latitudes sampled in common with *latifolia*.

Latifolia—Ultimate tensile stress (table III-3) of specimens from latitude 50 degrees (6,720) averaged significantly higher than in those from 47.5 degrees (4,970), 45 degrees (4,770), 57.5 degrees (4,720), 40 degrees (4,120), and 42.5 degrees (4,060).

Ultimate tensile stress in specimens from the southernmost two zones (40 degrees and 42.5 degrees) averaged significantly lower than in specimens from 50 degrees and more northerly latitudes.

[1]Data under these headings are from Pellerin and others (in preparation).

Additionally, ultimate tensile stress was inversely correlated with elevational zone, as follows:

Elevational zone	Ultimate tensile stress
	Lb/in²
Low	5,590
Medium	5,390
High	4,500

Ultimate tensile stress in the doweled sections was positively correlated with dynamic modulus of elasticity of the unmachined sections (fig. III-15). The lower 5 percent exclusion limit for the ultimate tensile stress values was 2,035 lb/in², from which a design value of tension parallel to the grain of 970 lb/in² can be derived. When the stem sections were screened by dynamic modulus of elasticity to various threshold values, lower 5 percent exclusion limits and design values were as follows:

Dynamic MOE threshold	Tensile stress Average	Tensile stress 5 percent exclusion limit	Design stress
Million lb/in²	*Lb/in²*		
1.25	5,716	2,940	1,400
1.50	5,990	3,050	1,452
1.60	6,200	3,280	1,562

Compression Properties of Unmachined Stemwood Sections (United States)

As noted previously, flange failures in the pole joists tested were about evenly divided between tension and compression fractures. To provide additional statistical data descriptive of the variation in compression strength of dowels from small lodgepole pines within the major range of the species in the United States, a pair of dominant or codominant lodgepole pine trees 3.5 to 4 inches in d.b.h. were selected for sampling at each of 28 locations in seven western States (fig. 2-2 and table III-4). No trees were sampled in California because public land managers indicated that small lodgepole pine trees in that State were not in excess supply.

A 9-inch-long stem section was removed at 20 percent of tree height from each of the 56 trees. This height was selected because previous research (Koch 1987) showed that the specific gravity of stemwood sampled at 20 percent of tree height closely approximates the average for entire stemwood (fig. III-10).

These stem sections were debarked, air-dried, lathe-turned to 2¼ inches in diameter, and square-end trimmed to remove chuck marks.

All but two of the turned specimens included knot clusters. No knots exceeded 0.5 inch in diameter, and most measured 0.2 to 0.3 inch in diameter. Most were sound red knots, but some were encased.

At test, the specimens averaged 8.2 percent moisture content (based on ovendry weight), with standard deviation of 0.63 percentage points and range from 6.4 to 9.5 percent. Of the 56 specimens, 30 had at least one drying check, and 26 were check free.

Compresssion tests parallel to the grain were conducted according to ASTM D-198 (American Society for Testing and Materials 1972b) on the 60,000-pound universal testing machine of the University of Montana School of Forestry. The machine was fitted with a compressometer with 4-inch gage length and dial gage reading to 0.0001 inch. Moisture content at test and specific gravity (based on ovendry weight and volume at test) were determined.

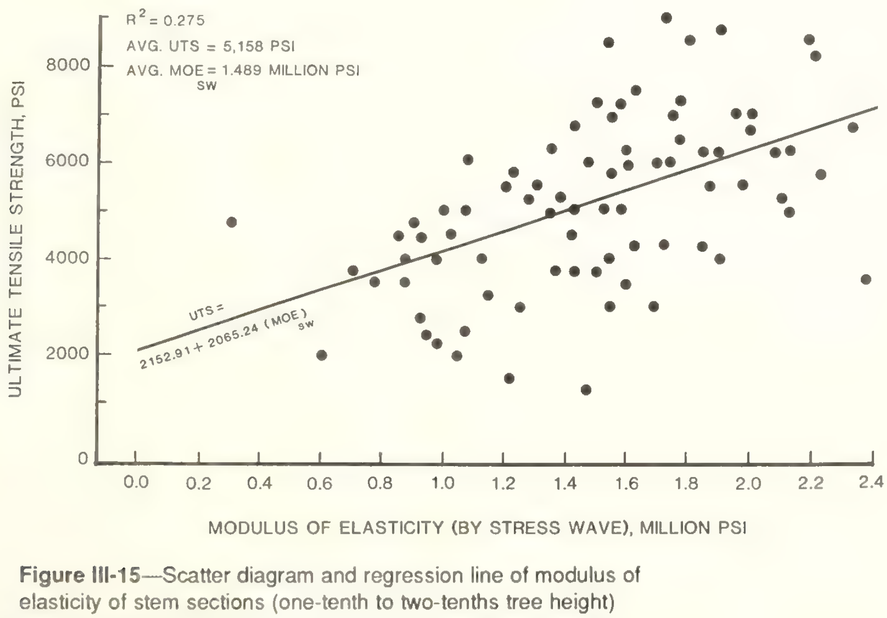

Figure III-15—Scatter diagram and regression line of modulus of elasticity of stem sections (one-tenth to two-tenths tree height) from 81 *latifolia* trees 3 inches in d.b.h. versus ultimate tensile stress of 2.25 inch-diameter pith-centered dowels turned from the stem sections Pellerin and others (in preparation).

Table III-4—Test-specimen characteristics tabulated by State averages and ranked by modulus of elasticity; standard deviations shown in parentheses (data from Koch and Barger 1988)

State	Number of specimens	Modulus of elasticity	Maximum crushing strength	Proportional limit	Specific gravity[1]	Rings per inch
		Million lb/in²	*Lb/in²*	*Lb/in²*		
Montana	10	1.63 (0.26)	7,120 (1,048)	4,930 (798)	0.492 (0.035)	32 (7)
Washington	8	1.24 (.26)	5,590 (827)	3,970 (568)	.442 (.038)	25 (12)
Wyoming	8	1.14 (.23)	5,430 (738)	3,550 (672)	.453 (.025)	36 (6)
Colorado	10	1.11 (.18)	5,690 (518)	4,340 (613)	.466 (.022)	56 (36)
Idaho	12	1.05 (.27)	5,340 (592)	3,410 (968)	.444 (.040)	20 (10)
Utah	2	1.02 (.60)	5,130 (92)	3,380 (806)	.413 (.004)	35 (16)
Oregon[2]	6	93 (.28)	5,300 (745)	2,530 (996)	.506 (.063)	28 (6)

[1]Based on ovendry weight and volume at 8.2 percent moisture content.
[2]Only the two specimens from the Malheur National Forest were free of compression wood; they had average modulus of elasticity of 1.24 million lb/in², with specific gravity of 0.456 and 23 rings per inch.

The compressometer was placed so that the knot cluster present in each specimen (except for two which were knot free) was within the gage length.

Values for modulus of elasticity, maximum crushing strength, and proportional limit were adjusted to a specimen moisture content of 10 percent by the procedure specified in ASTM D-2915 (American Society for Testing and Materials 1972a).

Mechanical properties, in compression parallel to the grain, of the 56 specimens gathered from the 28 areas in seven States are summarized as follows (values adjusted to a specimen moisture content of 10 percent of ovendry weight):

Property	Average value	Standard deviation	Range
	Lb/in²		
Modulus of elasticity	1,190,000	320,000	640,000-2,090,000
Maximum crushing strength	5,760	967	4,280-8,730
Proportional limit	3,850	1,039	1,060-6,080

The data (see Koch and Barger 1988, appendix) suggest that mechanical properties in compression parallel to the grain are not closely related to specific gravity, rings per inch, or the presence of drying checks.

This lack of correlation with specific gravity is largely attributable to the presence of knot clusters in the specimens and, more important, to the sporadic presence of compression wood. Compression wood generally has high specific gravity, but—in dry wood—low mechanical properties. Also, trees that are fast growers may have more compression wood than the slow growers. For example, the two trees sampled from the Pinhead Butte area of the Mt. Hood National Forest in Oregon both had much compression wood and had average modulus of elasticity of only 760,000 lb/in², with proportional limit of only 1,460 lb/in², even though they had the highest specific gravity of any trees sampled (average 0.580); these two specimens had 32 and 26 rings per inch.

Differences in mechanical properties between specimens free of compression wood and those with compression wood readily visible in sanded cross sections are indicated in the following tabulation:

Property	No visible compression wood (42 specimens)	Visible compression wood (14 specimens)
	Lb/in²	
Modulus of elasticity		
Average	1,270,000	940,000
Standard deviation	299,000	250,000
Range	870,000-2,090,000	640,000-1,430,000
Maximum crushing strength		
Average	5,920	5,250
Standard deviation	986	722
Range	4,280-8,730	4,390-6,770
Proportional limit		
Average	4,130	3,030
Standard deviation	855	1,134
Range	2,620-6,080	1,060-5,110

While data are far from adequate to characterize small lodgepole pines in the several States studied—particularly those of Utah where only two trees were sampled—a ranking of the States by specimens' average modulus of elasticity suggests that lodgepole pine in Montana's study areas have superior mechanical properties (table III-4).

Implications of Geographic Variations

Study of the variation in specific gravity, and tension and compression properties of lodgepole pines sampled broadly within the North American range of the species, suggests that these physical and mechanical properties of stemwood from small trees are maximum, or near maximum, in northwestern Montana close to the Canadian border. Additionally, data available on mechanical properties of stemwood from seven northwestern States (table III-4) support this conclusion.

III-7 VARIATION IN MODULUS OF ELASTICITY OF LODGEPOLE PINE DOWELS FROM NORTHWESTERN MONTANA (LATITUDE 48.5 DEGREES)

As noted in section 4-1, Burke and Koch (1987) collected 152 small lodgepole pines in the Libby to West Glacier area of Montana, and from these stems turned 16-foot-long dowels with green diameters of 2.25 and 2.50 inches—76 of each diameter. The 2.25 inch dowels had average specific gravity of 0.42; dowels 2.50 inches in diameter had average specific gravity of 0.43—both values based on ovendry weight and green volume.

Modulus of elasticity data gathered on these dowels, by nondestructive evaluation in flexure over a 15-foot span with center-point loading, are summarized as follows:

Moisture content and statistic	**Dowel diameter 2.25 inches**	**2.50 inches**
	Million lb/in²	
Green		
Average	1.446	1.553
Standard deviation	.235	.195
Range	0.937-2.026	1.081-1.985
10 percent moisture content		
Average	1.739	1.850
Standard deviation	.262	.251
Range	1.16-2.376	1.322-2.460

The 2.50-inch dowels had slightly higher average modulus of elasticity than the 2.25-inch dowels.

Distributions of values were more-or-less normal (figs. 4-1 and 4-2).

III-8 SEMISQUARING OF DOWELS—EFFECT ON MECHANICAL PROPERTIES

Because of the need to use blocking in lengths precision trimmed to fit between joists, it was deemed desirable that flanges be machined to a precise width in addition to being flattened on top to provide a nailing surface and provided with a dado groove for the web (fig. III-16). It was surmised that this additional machining would further reduce the mechanical properties of the dowels. To evaluate the anticipated effect, end-matched replicates of cylindrical and semisquared and grooved (fig. III-16) dowels 2.25 and 2.50 inches in diameter (green dimensions) were prepared in 6-inch lengths and tested (when dry) in compression parallel to the grain.

Average modulus of elasticity of the semisquared and grooved dowels was less than that of the cylindrical dowels. Missing data in the 2.5-inch tabulation (table III-5) makes evaluation difficult, but it is probable that semisquaring and grooving operations reduce MOE by at least 5 percent, and possibly more.

Ultimate crushing stress was little affected (table III-5).

III-9 FIRST APPROXIMATION OF JOIST DESIGNS—DESTRUCTIVE TESTS OF 63 JOISTS

To gather empirical data that would give some indication of the joist dimensions required to meet the target properties outlined in table 3-3, the dowels with green diameters of 2.25 and 2.50 inches described in section III-7 were machined to the cross sections depicted in figure III-16. At time of machining, the dry dowels averaged 2.15 and 2.38 inches in diameter. They were paired by modulus elasticity class (so that both flanges in a joist had approximately equal moduli of elasticity) and assembled with 3/8-inch-thick webs of lodgepole pine oriented strand board manufactured in an Idaho plant. This oriented strand board weighed about 39.3 lb/ft³ at a moisture content of 10 percent of ovendry weight. Flake thickness and resin content are unknown.

The joists were loaded to failure with 15 feet between supports in edgewise flexure on a 60,000-pound universal testing machine equipped with lateral supports to preclude buckling. The load was applied at two points 60 inches apart and symmetrical about the midlength of the joist. Roller nests were used under both end supports, and a roller nest was placed under one head to ensure that loading was vertical (fig. 3-3). The apparatus and speed of vertical movement of the loading head followed recommendations of American Society of Testing and Materials (1972b).

The joists failed to meet the target values (table 3-3) for EI and design resistive moment; summary statistics derived from table III-6 were as follows:

Joist depth (fig. III-16)	**EI**	**Design resistive moment**
Inches	*Million inch² pounds*	*Foot pounds*
9 1/2	132	2,468
11 7/8	288	3,665

EI and maximum resistive moment of the joists were unrelated to numerical visual grades assigned to the dowels on the basis of their knot structure (R^2 values were less than 0.12). Also, severity of drying checks in the dry flange dowels (numerically rated) was unrelated to EI or maximum resistive moment.

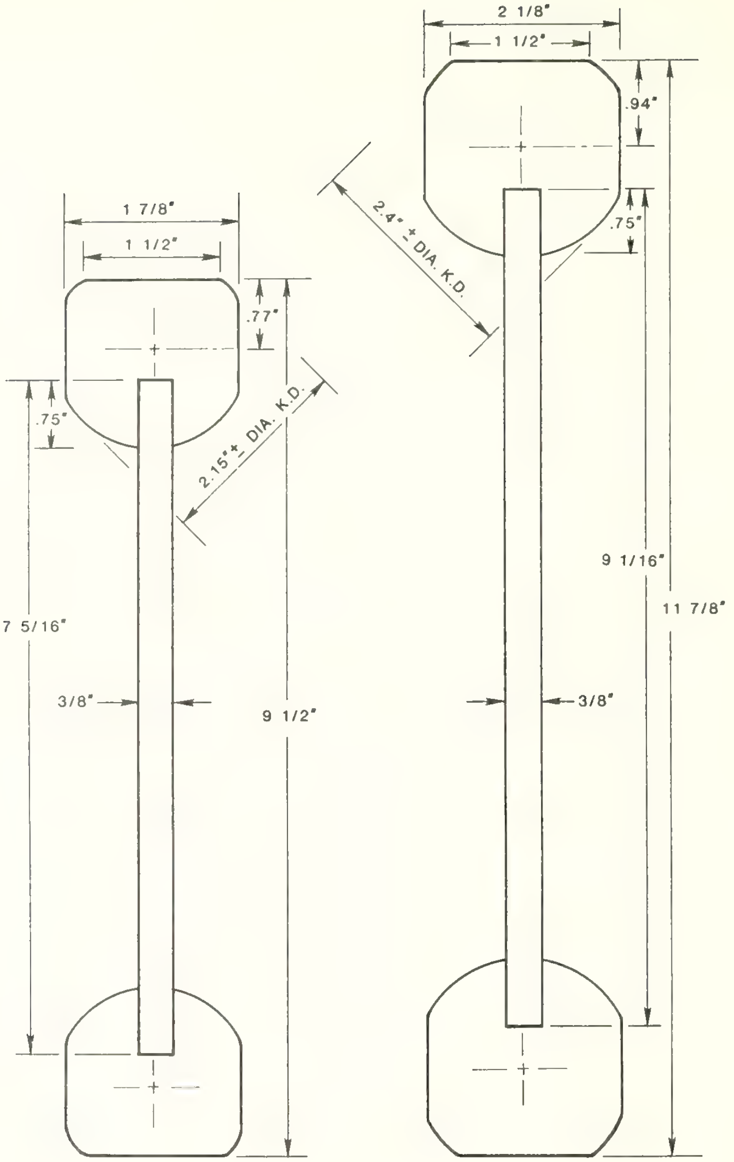

Figure III-16—Joists fabricated $9^1/2$ and $11^7/8$ inches deep, with lodgepole pine pith-centered dowels for flanges and three-eights inch OSB for webs.

Table III-5—Effect on mechanical properties[1] in compression parallel to the grain of semisquaring and grooving—when dry, dowels turned green to 2.25 and 2.50 inches in diameter (fig. III-16)

Specimun number, average, standard deviation	Doweled but not otherwise machined		Semisquared and grooved	
	MOE	Maximum crushing stress	MOE	Maxmum crushing stress
	Million lb/in²	*Lb/in²*	*Million lb/in²*	*Lb/in²*
		Dowels 2.25 inches in diameter		
1	1.014	3,838	0.943	5,030
2	.907	3,887	.893	3,983
3	.914	4,363	.802	3,550
4	.747	3,594	.923	3,383
5	.887	4,727	.956	4,731
6	1.055	4,281	1.098	3,989
7	.888	3,222	.720	3,244
8	1.304	5,192	1.054	4,735
9	1.405	4,200	1.108	4,281
10	1.171	4,637	1.396	4,500
Average	1.029	4,194	.989	4,143
Std. dev.	.207	581	.189	616
n	10	10	10	10
		Dowels 2.50 inches in diameter		
1	2.125	8,144	2.039	9,817
2	1.398	6,286	1.420	6,027
3	1.742	7,445	—	7,383
4	2.737	5,973	1.925	6,286
5	1.826	5,427	—	6,528
6	2.775	6,346	1.487	5,043
7	2.640	5,138	1.781	4,359
8	—	5,675	1.609	4,901
Average	2.178	6,304	1.710	6,293
Std. dev.	.549	1,023	.246	1,730
n	7	8	6	8

[1]Values adjusted to a specimen moisture content of 10 percent of ovendry weight.

Table III-6—Maximum resistive moment and EI of pole joists 9.5 and 11.875 inches deep (fig. III-16), ranked by average modulus of elasticity of the two dowel flanges of each joist (before they were semisquared and grooved); all values adjusted to 10 percent moisture content[1]

Joist	Maximum resistive moment	EI	MOE of dowels (average of both)	Failure type[2]
Number	*Foot-pounds*	*Million inch² pounds*	*Million lb/in²*	
		9.5-inch-deep Joists		
1	8,750	147.029	2.233	C
2	7,975	165.371	2.215	S
3	6,925	173.580	2.162	S
4	7,500	128.126	1.980	C
5	8,750	141.197	1.944	S
6	8,425	150.900	1.939	S
7	7,800	125.493	1.858	T
9	8,400	153.879	1.880	S
8	8,100	119.927	1.802	C
10	7,950	125.362	1.791	C
15	7,425	131.406	1.779	T
16	8,100	124.980	1.770	C
11	7,938	144.230	1.764	T
12	7,750	143.488	1.732	T
13	8,750	128.409	1.719	T
14	6,925	134.051	1.702	S
17	6,938	115.496	1.690	C
18	7,175	110.421	1.688	T
19	5,625	121.042	1.658	T
20	6,975	134.937	1.651	C
21	7,000	127.651	1.628	T

(con.)

Table III-6—(Con.)

Joist	Maximum resistive moment	EI	MOE of dowels (average of both)	Failure type[2]
Number	*Foot-pounds*	*Million inch² pounds*	*Million lb/in²*	
23	8,000	134.805	1.640	T
24	7,950	135.943	1.612	S
22	5,100	122.675	1.606	C
25	7,125	120.269	1.582	T
26	5,925	129.709	1.522	T
28	8,450	121.119	1.416	C
27	8,050	119.166	1.414	C
29	4,700	106.047	1.340	T
30	7,875	119.588	1.242	T
Average	7,478	131.877	1.732	
Std. dev.	1,034	15.350	.235	
Range	4,700-8,750	106-174	1.242-2.233	
95 percent exclusion limit[3]	5,183	—	—	
Design value[4]	2,468	131.877	—	
		11.875-inch-deep Joists		
1	11,298	303.707	2.416	T
2	12,833	332.478	2.239	T
3	10,625	263.385	2.134	C
4	9,375	313.499	2.087	?
5	13,925	328.887	2.084	S
6	12,750	316.446	2.044	S
7	13,750	303.917	2.031	T
8	12,688	394.413	2.017	T
9	12,625	360.104	1.989	T
10	11,875	291.627	1.959	T
12	9,000	319.112	1.924	T
11	11,325	255.701	1.907	T
13	11,500	278.587	1.868	T
14	12,000	321.560	1.861	C
15	13,000	268.640	1.851	T
16	8,650	308.395	1.851	T
18	10,500	270.993	1.852	S
17	11,000	348.783	1.805	?
19	11,375	279.050	1.786	C
20	11,625	302.596	1.785	C
22	9,250	267.809	1.783	C
21	10,950	308.397	1.728	C
23	10,625	295.124	1.726	C
24	8,800	287.729	1.690	T
28	10,688	261.330	1.675	S
25	10,375	239.878	1.654	?
26	11,750	246.967	1.626	?
27	7,938	274.778	1.612	T
30	11,438	267.292	1.570	C
29	10,250	208.488	1.525	C
31	10,500	204.786	1.456	T
32	9,075	237.878	1.406	T
33	9,500	227.033	1.341	T
Average	10,996	287.557	1.826	
Std. dev.	1,508	42.095	.239	
Range	7,938-13,925	205-394	1.341-2.416	
95 percent exclusion limit[3]	7,696	—	—	
Design value[4]	3,665	287.557	—	

[1]Burke and Koch 1987

[2]See figure III-21

C = flange compression failure

T = flange tension failure

S = web interlaminar shear failure adjacent to flange-web joint

? = failure type not recorded.

[3]The probability is 95 percent that at least 95 percent of the maximum resistive moments (based on loads at failure) of the distribution from which this sample was drawn will exceed the values tabulated. These exclusion limits were calculated according to Natrella (1963).

[4]95 percent exclusion limit divided by 2.1.

Surprisingly, the joist EI values were not closely correlated with dry-dowel moduli of elasticity (fig. III-17). For joists 9 1/2 inches deep, $R^2 = 0.541$; for joists 11 7/8 inches deep, $R^2 = 0.427$. In other words, modulus of elasticity of the dry flange dowels, before semisquaring and grooving, accounted for only about half the variation in stiffness of the joists.

Maximum resistive moment of the joists had even less correlation with dry-dowel moduli of elasticity (fig. III-18). For joists 9 1/2 inches deep, $R^2 = 0.141$; for joists 11 7/8 inches deep, $R^2 = 0.229$.

III-10 THE FLANGE-WEB JOINT

Good integrity and strength of the flange-web joint is essential to attainment of high strength and stiffness in the entire joist. As described in section III-2, flakeboard webs of appropriate design probably yield stiffer and stronger joists than plywood webs of the same thickness. But flakeboard can be made with two different flake orientations (random and oriented), and in a range of densities—so generalities regarding performance of flakeboard webs must be made with caution.

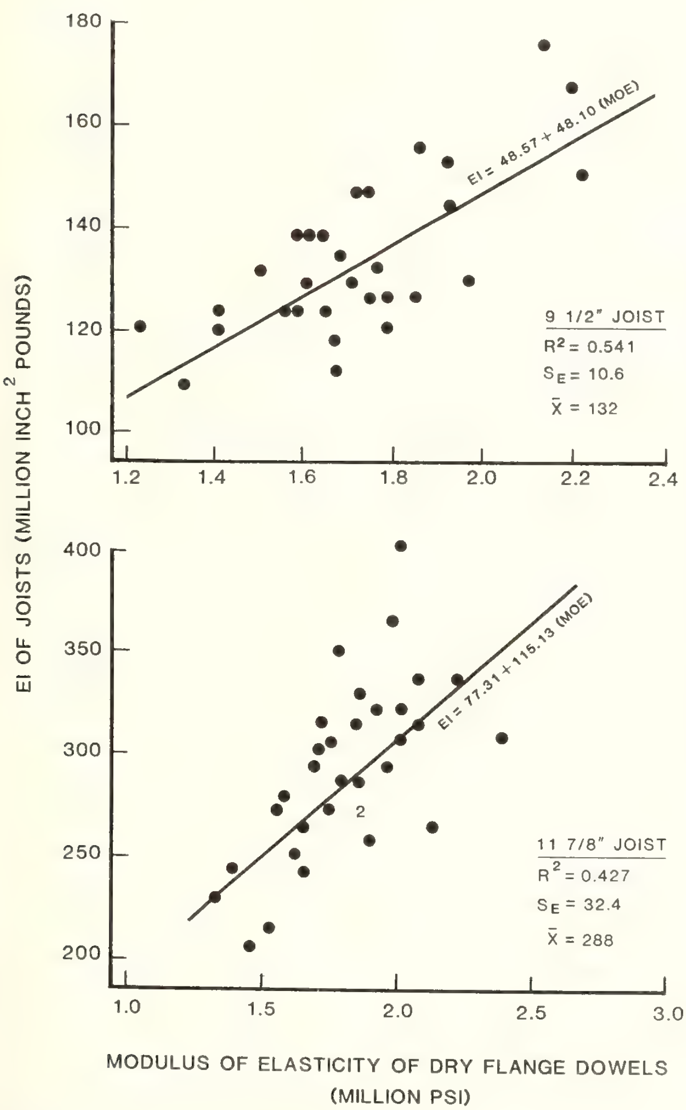

Figure III-17—Relationship between EI of pole joists and modulus of elasticity of flange dowels, both at 10 percent moisture content. (Top) Joists 9 1/2 inches deep. (Bottom) Joists 11 7/8 inches deep.

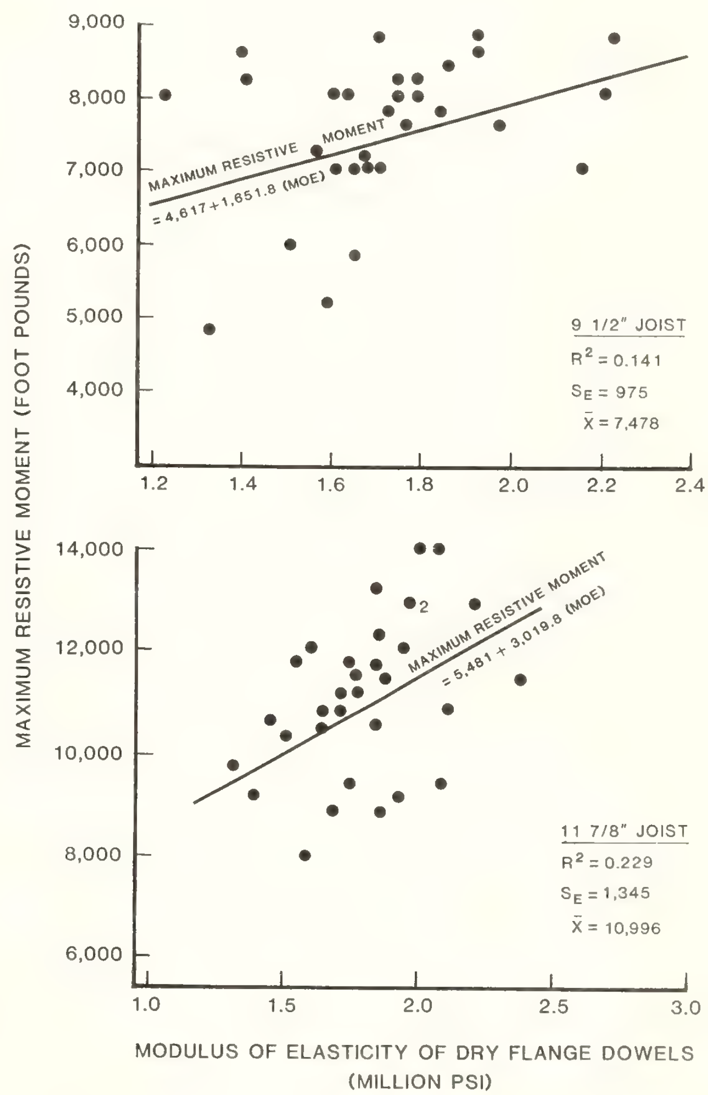

Figure III-18—Relationship between maximum resistive moment of pole joists and modulus of elasticity of flange dowels, both at 10 percent moisture content. (Top) Joists 9 1/2 inches deep. (Bottom) Joists 11 7/8 inches deep.

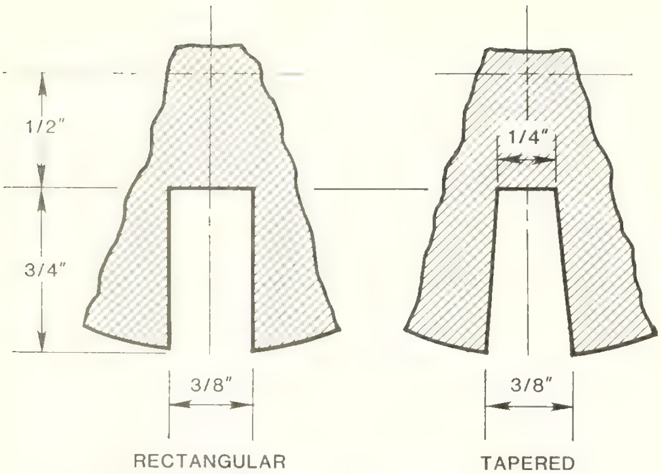

Figure III-19—Comparison of rectangular and tapered grooves for web-flange joint.

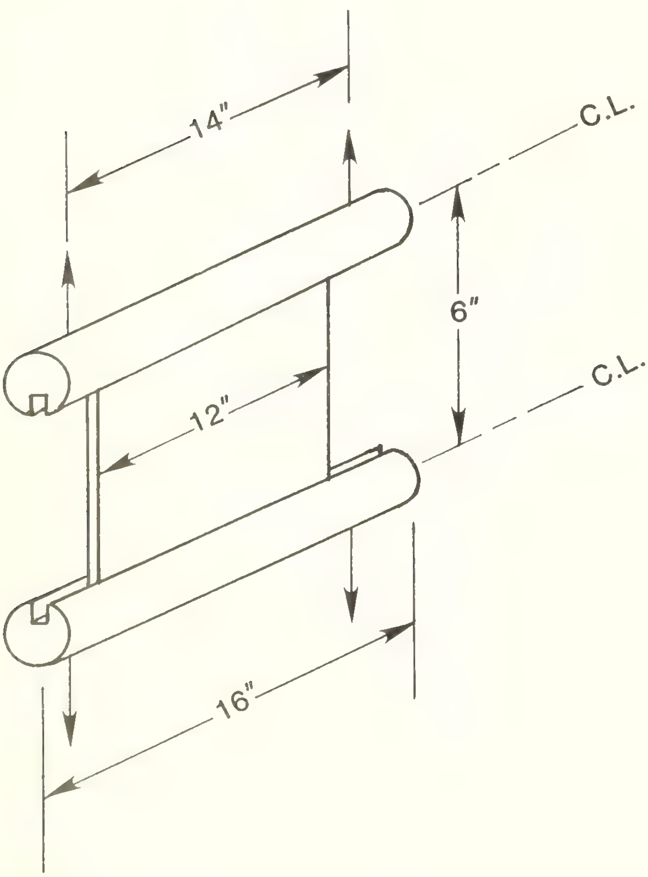

Figure III-20—Specimen and loads applied to evaluate strength of web-flange joints.

Additionally, the dado groove in the flange (and web edge) can be rectangular (fig. III-16) or tapered (fig. III-19). In an effort to obtain some empirical data on the strength of various designs, a two-factor experiment was executed in which the various flange-web joints were glue-assembled and tested to failure in tension (fig. III-20). In this experiment factors were as follows:

Type of flakeboard:	Lodgepole pine OSB with face flakes vertical in joist
	Aspen flakeboard with random orientation of flakes (it was necessary to use aspen because random flake arrangement was not available in lodgepole pine)
Shape of dado groove and web edge:	Rectangular, 0.75-inch deep Tapered, 0.75-inch deep
Replications:	6 to 8

This simple tension test—which yields stresses only partially similar to those incurred in a loaded joist—suggested that there is little difference in strength (stressed as depicted in figure III-20) between joints made with oriented strand board and random flakeboard webs, or between joints made with rectangular and tapered grooves (table III-7).

Because random flakeboard has higher inplane shear strength than oriented strand board of the same density, and because the tapered joint is easier to assemble and has more tendency to self lock on assembly than the rectangular joint, webs with random flake arrangement and tapered joints were chosen for the proposed commercial designs (fig. 3-2, page 28).

III-11 PROOF TESTS OF PROPOSED COMMERCIAL DESIGNS (50 JOISTS)

Based on all of the foregoing discussion, the proposed commercial designs (fig. 3-2) utilize dowels turned when green to a diameter of 2.69 inches (yielding a diameter of about 2.60 inches when dowels are dried to 8 to 10 percent moisture content). A web of $^3/_8$-inch-thick flakeboard with randomly oriented flakes has edges tapered to match tapered dado grooves (figs. 3-2 and III-19, right) in the semicylindrical flanges. (The aspen waferboard with randomly oriented flakes used for proof tests had density of 42.5 lb/ft^3 at 3.45 percent moisture content and averaged 0.365 inch in thickness.)

The lodgepole pine trees utilized for flange dowels in the proof tests were sampled about 25 miles east of Libby, MT, from the Miller Creek drainage. Summary statistics on these dowels are tabulated at the end of section 4-1 and graphed in figures 4-3 through 4-7.

Table III-7—Maximum load sustained in tension (fig. III-20) by flange-web joints with two groove types and two types of flakeboard webs 3/8-inch thick

Replication	Rectangular dado groove: OSB[1]	Rectangular dado groove: Random flake arrangement[2]	Tapered dado groove: OSB[1]	Tapered dado groove: Random flake arrangement[2]
	- - - - - *Pounds* - - - - -		- - - - - *Pounds* - - - - -	
1	1,810	1,690	1,080	1,670
2	1,810	1,300	1,520	1,860
3	1,270	1,530	1,590	1,680
4	1,730	1,670	1,370	2,060
5	1,540	1,370	1,500	1,580
6	1,370	1,490	1,880	1,430
7	1,890	—	1,720	1,480
8	—	—	1,660	1,410
Average	1,631	1,508	1,540	1,646
Std. dev.	241	157	241	225
n	7	6	8	8

[1]Lodgepole pine OSB weighing 39.9 lb/ft^3 at test moisture content of about 6 percent of ovendry weight. Flange moisture content was about 8 percent. Face flakes were oriented vertically in the test section, that is, perpendicular to the grain of the flange.

[2]Aspen flakeboard with random flake arangement, and weighing 43.2 lb/ft^3 at test moisture content of 7 to 8 percent of ovendry weight. Flange moisture content was about 8 percent.

Dry dowels with modulus of elasticity of less than 1.5 million lb/in^2 were rejected as unsuitable for flanges. The suitable dowels had average static modulus of elasticity measured in bending (center-point loading over a 15-foot span) of 1.999 million lb/in^2, with range from 1.526 to 2.841 million lb/in^2. By MOE class (at 10 percent moisture content), distribution of values for the 100 suitable dowels was as follows:

MOE class	Number of dowels
Million lb/in^2	
1.50-1.59	4
1.60-1.69	9
1.70-1.79	11
1.80-1.89	14
1.90-1.99	14
2.00-2.09	13
2.10-2.19	13
2.20-2.29	10
2.30-2.39	6
2.40-2.49	2
2.50-2.59	2
2.60-2.69	1
2.70-2.79	0
2.80-2.89	1
Total number	100

To provide a statistical basis for determining design values of mechanical properties of the proposed commercial joists, twenty 10-inch, twenty 12-inch, five 14-inch, and five 16-inch joists 16 feet long were fabricated (fig. 3-2), with these 100 selected flange dowels randomly paired for each joist. The 50 joists were then tested in bending to destruction with center-point loading over a 15-foot span. Results are summarized in table III-8.

III-12 CONCLUSIONS (FROM TABLE III-8)

Three parameters are of particular interest to designers of structural systems utilizing fabricated joists: stiffness (EI), design values for maximum allowable vertical shear loads, and design values for maximum allowable resistive moment.

Stiffness (EI)

Measured joist EI averaged about 79 percent of the product of cylindrical flange-dowel MOE and moment of inertia of flattened and grooved flange-pairs only as spaced in joists of the four depths, but this percentage varied inversely with joist depth, as follows:

Joist depth	Average flange MOE	Flange-pair I
Inches	*Million lb/in^2*	*Inch^4*
10	1.986	149.0
12	2.060	235.2
14	1.941	340.9
16	1.858	466.1

Measured EI (table III-8)	Flange- pair I times flange MOE	Ratio
Million inch^2 pounds	*Million inch^2 pounds*	*Percent*
253	296	85.5
387	485	79.8
516	662	77.9
636	866	73.4
		Average 79.2

Vertical Shear

The twenty 12-inch joists all failed in interlaminar web shear, with values approximating a normal distribution. Only six of the twenty 10-inch joists failed in interlaminar web shear (plus one by web buckling), but if the conservative assumption is made that all 20 supported maximum loads in shear equal to the values tabulated in table III-8, the distribution of these values is as follows:

Maximum-load class	10-inch joists	12-inch joists
Pounds	*Number*	
4,100-4,299	ii	i
4,300-4,499	iii	
4,500-4,699	ii	ii
4,700-4,899	iiiii	iiii
4,900-5,099	ii	iiiii
5,100-5,299	i	iii
5,300-5,499	i	i
5,500-5,699	iii	i
5,700-5,899		ii
5,900-6,099		i

If normality of distribution of these maximum loads is accepted, the procedure of Natrella (1963) can be applied to calculate the 95 percent exclusion limits of maximum center-point loads at web shear failure. Thus the probability is 75 percent that at least 95 percent of the maximum center-point loads at web shear failure of the distribution from which this sample was drawn will exceed the following values:

10-inch $4,869 - 1.933 \times 463 = 3,974$ pounds
12-inch $5,097 - 1.933 \times 464 = 4,200$ pounds

These center-point loads correspond to the reaction-point loads (vertical shear loads) and design vertical shear loads—that is, the 95 percent exclusion limit divided by the factor 2.1, as follows:

Joist depth	95 percent exclusion limit for reaction-point load	Design value for vertical shear
Inches	*Pounds*	*Pounds*
10	1,987	946
12	2,100	1,000

Numbers of 14-inch and 16-inch joists tested were insufficient to establish the design values for maximum shear, but the averages (table III-8) suggest that they will sustain no more vertical shear load (and possibly less) than the 12-inch joists. Pending additional tests, the design vertical shear load for the 14-inch and 16-inch joists is assumed to be 1,000 pounds.

Design Resistive Moment

The design value for maximum resistive moment of the 10-inch joists can be conservatively estimated from the center-point loads at failure (table III-8) by Natrella's (1963) procedure for computing the 95 percent exclusion limit (at 75 percent probability), dividing this value by 2 to get the reaction-point load, multiplying by the 7.5-foot moment arm, and dividing the result by the factor 2.1. This procedure yields a design resistive moment for the 10-inch joist as follows:

$[(4,869 - 1.933 \times 463)/2] \times 7.5/2.1 = 7,096$ foot pounds

Because all of the joists 12, 14, and 16 inches deep failed by interlaminar web shear, their design resistive moments must be computed from the maximum fiber stress in the 10-inch joists at design resistive moment. Because all flange dowels were randomly drawn from the same dowel population (compare flange MOE's for the four joist depths to perceive this comparability), it is reasonable to assume all can safely carry this same extreme fiber stress at design resistive moment.

For the 10-inch joists, this extreme fiber stress (S) is computed from the relationship:

$$S = MC/I$$

where:
M = design resistive moment, inch-pounds
C = distance from neutral axis to extreme fiber, inches
I = moment of inertia of the flange pair (ignoring web), inches^4

Thus:
$S = (7,096 \times 12)(5)/149.0 = 2,857$ lb/in^2

Design resistive moments can then be computed as follows:

Joist depth	Design S	I of flange-pair
Inches	*Lb/in²*	*Inches⁴*
10	2,857	149.0
12	2,857	235.2
14	2,857	340.9
16	2,857	466.1

Joist depth	C	Design resistive moment SI/C	Design resistive moment SI/C
Inches	*Inches*	*Inch-pounds*	*Foot-pounds*
10	5	85,152	7,096
12	6	111,994	9,333
14	7	139,136	11,595
16	8	166,456	13,871

III-13 SUMMARY

Table III-9 summarizes important properties of joists (fig. 3-2) of the four depths.

These data indicate that the joists proposed (fig. 3-2) warrant acceptance by major building code agencies because of their light weight and the uniformity and predictability of their mechanical properties. Probably greater numbers of the joists must be built in longer lengths (incorporating finger joints in the flange dowels) and tested, but the authors are confident that the properties outlined in table 3-3 can be achieved.

Among other things, the data show that small lodgepole pine in northwestern Montana have outstanding mechanical properties for the species. The Libby-Troy area is an optimum site for a manufacturing plant that would utilize this raw material.

Table III-8—Data on 16-foot-long fabricated joists 10, 12, 14, and 16 inches deep (fig. 3-2) static tested in bending over a 15-foot span with center-point loading, and data on the dowels comprising their flanges[1,2]

	Joist data				Flange data[3]		
Joist number	EI[4]	Maximum load[4]	Failure type[5]	O.D. weight per lineal foot	MOE[4]	Specific gravity[6]	Rings per inch
	Million inch² pounds	*Pounds*		*Pounds*	*Million lb/in²*		
			110-inch-Deep Joists				
1	303	5,605	S	2.67	2.262-2.197	0.461-0.438	23-18
2	247	4,540	T	2.53	1.555-2.107	0.407-0.442	15-18
3	243	4,867	S	2.62	2.254-1.711	0.454-0.406	19-15
4	231	4,781	T	2.64	1.744-1.913	0.434-0.466	14-13
5	238	4,486	T	2.54	1.524-2.121	0.381-0.450	14-19
6	257	5,494	T	2.59	1.879-2.012	0.409-0.438	19-15
7	267	4,822	T	2.73	1.765-2.484	0.414-0.478	12-23
8	268	4,767	C	2.60	2.299-1.994	0.448-1.424	20-20
9	241	5,279	T	2.57	1.822-1.803	0.421-0.431	12-18
10	230	4,907	C	2.57	2.115-1.526	0.449-0.404	14-18
11	263	4,236	T	2.41	1.668-1.849	0.387-0.384	13-16
12	247	4,436	T	2.67	1.885-1.966	0.460-0.428	14-19
13	242	5,585	S	2.55	2.157-1.787	0.413-0.423	17-17
14	275	4,594	S	2.74	1.771-2.610	0.416-0.498	18-23
15	248	5,051	S	2.56	2.226-1.759	0.436-0.408	16-14
16	240	4,332	T	2.60	1.594-2.564	0.389-0.464	12-24
17	269	5,689	B	2.74	2.457-2.053	0.489-0.432	24-16
18	244	4,870	C	2.58	1.946-1.864	0.410-0.436	16-12
19	253	4,898	C	2.66	2,358-1.693	0.447-0.426	19-12
20	263	4,143	S	2.59	2.093-2.030	0.417-0.429	21-16
Average	253	4,869		2.61	1.969-2.002	0.427-0.435	16.6-17.3
Std. dev.	17.5	463		0.08	0.288-0.289	0.028-0.027	3.6-3.5
Range	230	4,143		2.41	1.524 1.526	0.381 0.384	12 12
	to	to		to	to to	to to	to to
	303	5,689		2.74	2.457 2.610	0.489 0.498	24 23
			12-inch-Deep Joists				
1	387	5,802	S	2.82	2.146-1.931	0.437-0.409	17-17
2	378	6,095	C?	2.81	2.134-1.754	0.451-0.429	15-13
3	378	5,061	S	2.86	1.791-2.159	0.463-0.430	14-15
4	387	5,770	S	2.89	2.111-2.090	0.458-0.435	15-15
5	452	4,160	S	2.83	2.168-2.145	0.425-0.455	17-14
6	388	5,254	S	2.80	2.025-2.238	0.429-0.437	15-20
7	384	5,162	S	2.83	2.016-1.899	0.446-0.426	15-18
8	372	4,913	S	2.85	1.675-2.267	0.407-0.467	12-14
9	408	5,284	S	2.89	2.336-2.083	0.458-0.435	20-13
10	361	4,638	S	2.78	2.122-1.990	0.410-0.430	14-21
11	368	4,711	S	2.78	1.638-2.295	0.405-0.439	18-19
12	404	4,709	S	2.97	2.029-2.281	0.468-0.468	18-22
13	437	5,061	S	2.92	2.275-2.133	0.467-0.462	20-18
14	390	4,660	S	2.94	1.815-2.578	0.426-0.488	13-23
15	363	4,879	S	2.85	1.925-1.909	0.455-0.438	13-15
16	412	5,617	S	3.00	2.841-1.809	0.515-0.422	24-18
17	375	5,028	S	2.81	1.767-2.055	0.431-0.426	15-19
18	359	4,941	S	2.68	2.054-1.817	0.414-0.401	15-16
19	348	4,858	S	2.77	1.912-2.041	0.425-0.413	17-17
20	383	5,342	S	2.83	1.843-2.286	0.393-0.454	18-18
Average	287	5,097		2.85	2.031-2.088	0.439-0.438	16.2-17.2
Std. dev.	25.7	464		.07	0.270-0.204	0.029-0.022	2.9-2.9
Range	348	4,160		2.68	1.638 1.754	0.393 0.401	12 13
	to	to		to	to to	to to	to to
	452	6,095		3.00	2.841 2.578	0.515 0.488	24 23

(con.)

Table III-8 (Con.)

Joist number	EI[4]	Maximum load[4]	Failure type[5]	O.D. weight per lineal foot	MOE[4] (Flange data[3])	Specific gravity[6] (Flange data[3])	Rings per inch (Flange data[3])
	Million inch² pounds	*Pounds*		*Pounds*	*Million lb/in²*		
14-inch-Deep Joists							
1	460	3,860	S	2.98	1.918-1.615	0.459-0.412	12- 8
2	558	4,396	S	2.94	1.653-1.818	0.408-0.444	9-10
3	530	4,979	S	3.00	2.086-2.247	0.424-0.440	16-15
4	494	—	-	2.95	1.670-2.182	0.402-0.439	14-17
5	538	5,456	S	3.20	1.867-2.355	0.416-0.477	12-18
Average	516	4,673		3.01	1.839-2.043	0.422-0.442	12.6-13.6
Std. dev.	38.9	694		0.11	0.181-0.313	0.022-0.023	2.6- 4.4
Range	460 to 558	3,860 to 5,456		2.94 to 3.20	1.653 to 2,086; 1.615 to 2.355	0.402 to 0.459; 0.412 to 0.477	9 to 16; 8 to 18
16-Inch-Deep Joists							
1	653	4,274	S	3.13	1.914-1.635	0.457-0.409	15- 9
2	560	5,522	S	3.19	1.638-1.819	0.404-0.455	11-11
3	645	4,911	S	3.23	1.983-1.936	0.448-0.437	12-18
4	620	4,384	S	3.09	1.736-1.856	0.410-0.415	13-19
5	700	4,932	S	3.20	1.736-2.322	0.400-0.465	13-16
Average	636	4,805		3.17	1.801-1.914	0.424-0.436	12.8-14.6
Std. dev.	51.2	500		0.06	0.142-0.254	0.027-0.024	1.5-4.4
Range	560 to 700	4,274 to 5,522		3.09 to 3.23	1.638 to 1.914; 1.635 to 2.322	0.400 to 0.457; 0.409 to 0.465	11 to 15; 9 to 19

[1]Burke, Edwin, J; Koch, Peter. 1987 January 9. Properties of 2¹/₄- and 2¹/₂-inch lodgepole pine dowels from northwest Montana stands and of 9¹/₂- and 11⁷/₈-inch-deep joists made with these dowels as flanges. Study WSL #19A. Unpublished data on file at Wood Science Laboratory, Inc. Corvallis, MT.

[2]Flanges were pith-centered lodgepole pine dowels measuring 2.60 inches in diameter when at 10 percent moisture content. Webs were aspen waferboard with random flake orientation, 0.365 inch thick, and weighing 40.5 lb/ft³ at 3.45 percent moisture content. At joist test, moisture content of the joist components averaged as follows (percent of ovendry weight): flanges 9.6 percent; webs 4.5 percent. Principally because web proportion increases with joist depth, moisture content of entire joists at test decreased with increased depth, as follows: 10-inch, 8.5 percent; 12-inch, 8.3 percent; 14-inch, 6.7 percent; and 16-inch, 6.5 percent.

[3]Tabulations in these columns show values for the tension flange followed by values for the compression flange. MOE of flanges was measure by non-destructively testing the dry dowels (before flattening of tops or grooving for webs) in bending over a 15-foot span with a 28-pound center-point load superimposed on a 10-pound preload.

[4]Static tested and values adjusted to correspond to a flange moisture content of 10 percent of ovendry weight according to procedures defined in American Society for Testing and Materials [ASTM} 1972a,1972b.

[5]See figure III-21.
C = flange compression failure
T = flange tension failure
S = web interlaminar shear failure adjacent to flange-web joint
B = web buckling failure adjacent to load head.

[6]Based on green volume and ovendry weight.

Table III-9—Summary tabulation of important properties of the proposed joists (fig. 3-2)

Property	10-inch	12-inch	14-inch	16-inch
Depth, inches	10	12	14	16
Weight per lineal foot, ovendry	2.61	2.85	3.01	3.17
Average EI, million inch² pounds	253	387	516	636
Maximum vertical shear at 100 percent of design load	946	1,000	1,000	1,000
Maximum resistive moment at 100 percent of design load, foot pounds	7,096	9,333	11,595	13,871

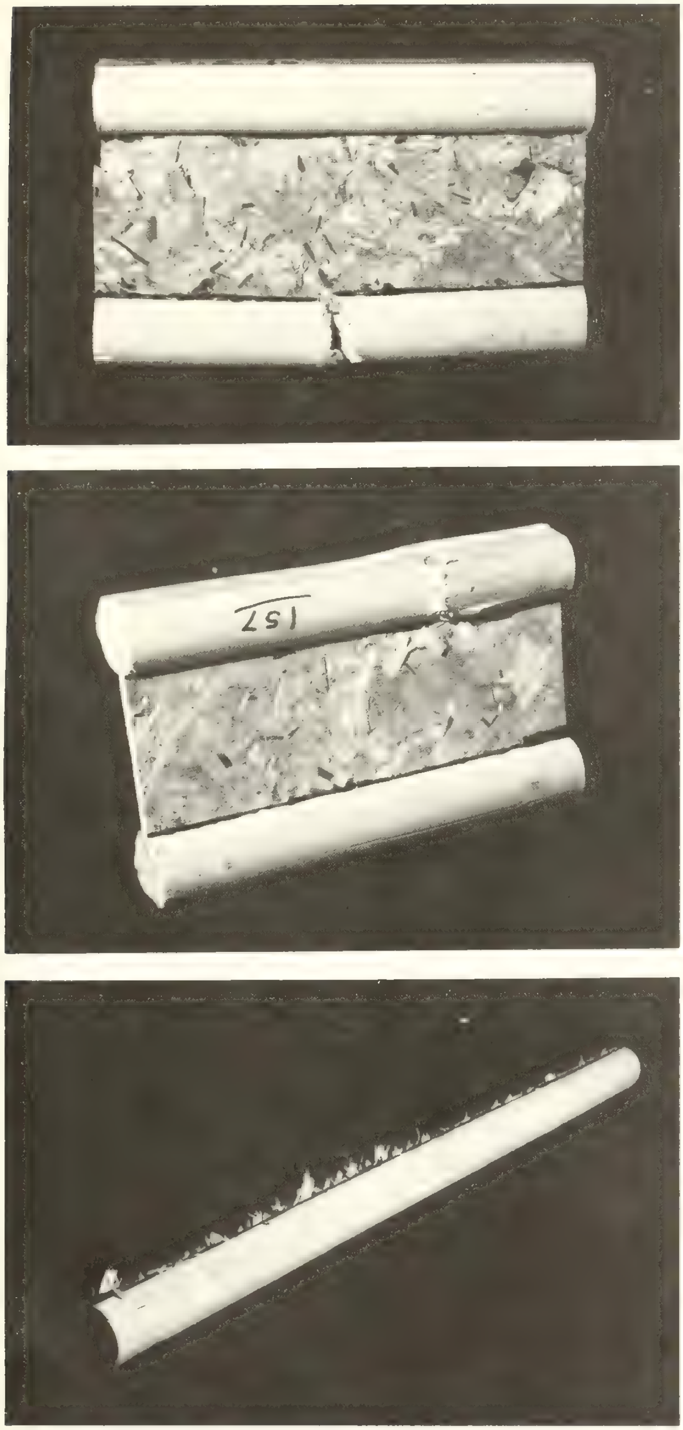

Figure III-21—Principal modes in which the fabricated joists failed under load. (Top) Flange tension failure. (Center) Flange compression failure. (Bottom) Web interlaminar shear failure in vicinity of web-flange joint.

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Describes and evaluates technical and economic feasibility of a proposed wood products plant utilizing sub-sawlog-size and dead lodgepole pine in northwestern Montana. Primary purpose of the plant is to facilitate harvesting and reforestation of vast, stagnated stands at minimal public expense. Annual stemwood consumption would total 200,000 tons, ovendry basis. Output would comprise fabricated joists, edge-glued panels for millwork, oriented-strand board, tree props, and studs. The plant would employ 271 mill workers, plus woods and transport workers. Capital investment is estimated to be $62 million; net annual sales, $40 million; after-tax annual rate of return, about 25.1 percent—based on an equity of $31 million (assuming an additional $31 million is raised through sales of bonds).

KEYWORDS: forest management, forest products, timber management, manufacturing plants, wood utilization, stand replacement, lodgepole pine, joists, millwork, flakeboard

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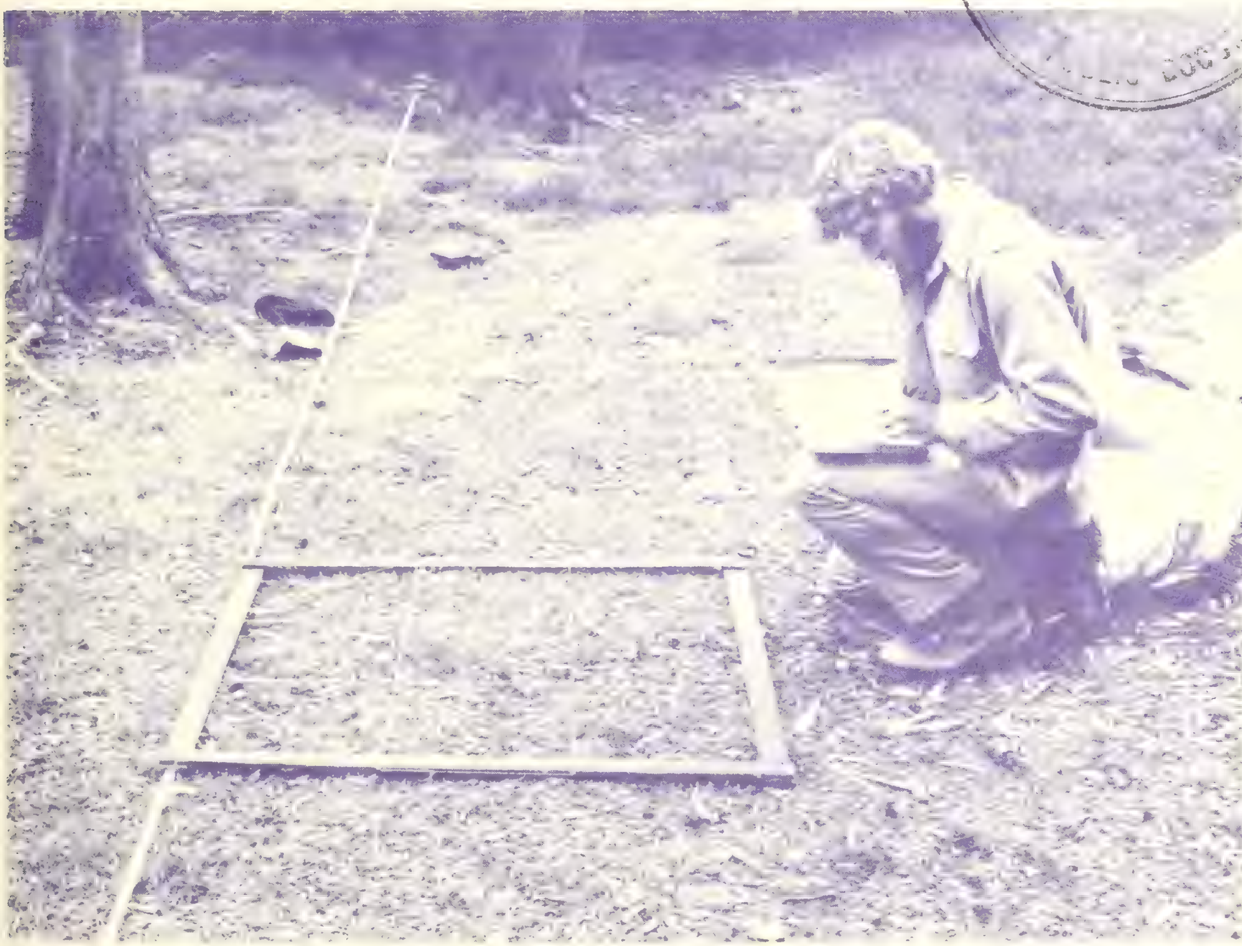
Wilderness Campsite Monitoring Methods: A Sourcebook

David N. Cole



THE AUTHOR

DAVID N. COLE is Project Leader and research biologist with the Intermountain Station's Wilderness Management Research Work Unit at the Forestry Sciences Laboratory on the University of Montana campus, Missoula. Dr. Cole received his B.A. degree in geography from the University of California, Berkeley, in 1972. He received his Ph.D., also in geography, from the University of Oregon in 1977. He has written many papers on wilderness management, particularly the ecological effects of recreational use.

PREFACE

The original objective of this report was to provide a handbook for managers on how to develop and use a campsite-monitoring system. The state of knowledge appeared to be sufficient to make this possible. As the project advanced, however, it became clear that many problems and unanswered questions remain. Therefore, the objective of the project turned toward compiling a summary of knowledge and identifying problems and areas in need of research. Managers able to recognize and modify ideas with merit and who are careful to avoid the problems identified should find useful techniques in this report. Managers looking for a system that can be applied without modification or creative application will find this report frustrating. Researchers should find the discussion of problems and needed research of value in identifying important projects.

The review and discussion that follows, then, is an attempt to summarize and evaluate experience with campsite monitoring systems, to identify situations where more research is needed, and to provide additional sources of information.

The discussion of existing systems purposefully is critical. My intent is to identify limitations and weaknessess, as well as to suggest useful approaches. Despite these shortcomings, those who have developed existing systems deserve much credit as pioneers in the field of monitoring. Others can learn from what has been accomplished and contribute to the development and use of increasingly effective monitoring systems. Finally, the opinions in this report are mine alone and as such are open to questioning, which I encourage.

RESEARCH SUMMARY

This report summarizes information on techniques that have been developed for monitoring campsites, particularly those in wilderness and backcountry. It is organized as a series of steps as follows: (1) evaluating system needs and constraints, (2) deciding on impact parameters and evaluation procedures, (3) testing of monitoring techniques, (4) training and documentation, (5) collecting field data , (6) analyzing and displaying data, and (7) applying data to management. For each step, existing techniques are described and evaluated, problems are discussed, and sources of information are listed. Detailed examples are included in a series of appendixes.

A wide variety of monitoring techniques have been developed. They range in format from photographic techniques to field measurement procedures of varying complexities. The techniques have been adapted to many diverse environments and many different types of impact. Experience in analyzing and using monitoring data is less developed. There is a critical need to develop low-cost monitoring systems with sufficiently high levels of precision. Opportunities for further research are numerous.

Intermountain Research Station
324 25th Street
Ogden, UT 84401

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Wilderness Campsite Monitoring Methods: A Sourcebook

David N. Cole

INTRODUCTION

According to the Wilderness Act of 1964, recreational use of wilderness is to be managed "so as to preserve its [the wilderness'] natural conditions" and such that "the imprint of man's work [is] substantially unnoticeable." Natural conditions have been most severely altered by recreational use on campsites. A first step that must be taken to control campsite impacts is to document campsite conditions and how they are changing over time. This information need has spurred considerable interest in the development of methods for monitoring campsites in wilderness and other backcountry areas.

The first publication to propose a specific method for systematically monitoring campsites was the Code-A-Site system (Hendee and others 1976). This was followed by a number of papers suggesting somewhat different approaches to campsite monitoring (Cole 1983a; Frissell 1978; Parsons and MacLeod 1980; Schreiner and Moorhead 1979). Since the publication of these reports, there has been considerable campsite monitoring activity—most of it unpublished and difficult to access.

This report discusses the monitoring technologies that have been developed for use on wilderness campsites and suggests where improvement is needed. The report is organized into a series of steps that must be taken in developing a monitoring system. The discussion of each step begins with a statement of purpose. For steps that require crucial decisions, a sequence of questions or issues that must be addressed is laid out. This is followed by a description of procedural details. Where there are alternative courses of action, the strengths and weaknesses of each alternative are discussed. Areas of needed research and development are highlighted, and finally, sources of additional information are suggested. Detailed descriptions of representative examples of monitoring approaches are included in an appendix.

STEP 1. EVALUATE SYSTEM NEEDS AND CONSTRAINTS

The purpose of this step is to determine what type of monitoring system is needed and feasible and to establish a priority for the monitoring effort. The procedure is as follows:

1. Establish the need for a campsite monitoring system.
2. Identify the most serious types of campsite impact.
3. Identify the types of information a monitoring system needs to provide.
4. Evaluate funding and work force constraints.
5. Decide among several alternative approaches to monitoring.

The product is the selection of a monitoring approach, a decision that carries with it certain implications for funding and work force needs.

Decision Making

The first question is, "Do I need a campsite monitoring program?" Any wilderness that receives overnight use probably needs monitoring. Even where campsites are currently perceived as satisfactory, conditions may deteriorate or it may be important to document conditions for those who feel that impacts are excessive. Monitoring systems are generally most necessary in places with large numbers of sites or severe campsite impacts, places where use patterns are unpredictable or in a state of flux, and places where campsite management programs are changing or have not been evaluated. The overall importance of monitoring is underscored by the fact that most wilderness areas meet at least some of these criteria. Nevertheless it is valuable to document, in a written format, how critical campsite monitoring is to management. This decision will guide later decisions about funding for monitoring, decisions that will influence the quality of the information collected.

A related question is, "How do I plan to use this information?" Management applications of monitoring data are discussed in a subsequent section of this report. If you can develop a clear picture of how monitoring data will be used, however, it will be easier to design an efficient system.

The next question is, "Do I need an inventory of all sites?" Systems can be established to monitor either a sample of sites or all sites in the area. Monitoring a sample of sites can identify the kinds of impacts that are occurring, as well as how conditions are changing over time. A carefully stratified sample can also provide information on how impacts and trends in impact vary with such factors as amount of use or location. But it is usually desirable to have information on changes in the number or spatial distribution of sites and information on the condition of all individual sites in the area. To obtain this information, a census of all sites is necessary.

If a census is not needed, sampling can reduce costs considerably. Several sites in each of a variety of environments and use situations (different amounts and types of use) could be examined. See such studies as Cole (1982, 1983b) and Marion (1984) for examples of this design—really more a research approach than monitoring.

The next question—regardless of the decision between a census and a sample—is, "How frequently do campsites need to be monitored?" It is unlikely that all campsites will need to be monitored every year. Once every 5 years seems to be a reasonable frequency for most situations. This is a long enough time for subtle changes to develop into measurable changes (at least on some sites), but a short enough time to identify impacts before they get out of control. Although many sites are unlikely to exhibit measurable changes, if the interval between observations is longer than 5 years, there is little opportunity to halt undesired changes. Appropriate monitoring frequencies must be decided on by each area.

Additional questions must be asked to decide which monitoring approach to adopt. One of those questions is, "What types of impact are of most concern and need to be monitored?" Although the nature of impacts on wilderness campsites does not differ greatly between areas, management objectives will differ, and this should be reflected in the types of impact that are monitored. From field visits to representative campsites and the experience of on-the-ground managers, the most important types of impact to monitor should be identified. Types of impact that can be monitored, along with specific procedures for each, are described in step 2.

Another question to address is, "About how many campsites are there to monitor?" Although there is relatively little variation between most wilderness areas in the need for monitoring, the types of impact that are occurring, and the importance of monitoring all sites, there can be pronounced differences in the number and accessibility of sites. Some areas have a small number of sites, either because camping is allowed only on designated sites or because use levels are low and only a few places are suitable for camping. Other areas have thousands of sites widely scattered over areas as large as several million acres. Obviously, monitoring systems can be less costly in those areas with fewer sites.

A rough guess about number of campsites, along with decisions about monitoring frequency and types of impact to monitor, are needed to answer the question, "How much time will it take to complete an inventory using each of the various alternative methods?" The basic monitoring approaches available are described below. These descriptions conclude with an estimation of the time requirements per site, recognizing that such estimates would vary greatly, particularly with the type and number of impact parameters being evaluated. Estimate time requirements for each of these approaches, without making an initial judgment about a preferred approach.

As an example, if an area has about 500 campsites, and they are to be inventoried every 5 years, 100 sites will have to be visited each year. A technique that takes two people 2 hours per site would require 400 staff-hours in addition to travel time. A technique that takes one person only 5 minutes would require only 8 to 9 person-hours in addition to travel time. It should be noted that, for many of these techniques, travel time may exceed the time spent monitoring. This makes differences in the time required for monitoring less critical. It also suggests the value of combining monitoring tasks with other tasks, such as patrol or cleanup, to make the most use of travel time.

With an estimate of the time it would take to get the job done using each of these techniques, the next question is, "How much time can I afford to spend on monitoring?" Funding levels for management of wilderness and backcountry differ greatly between areas, as does the proportion of those funds allocated to monitoring. Areas with more resources available and fewer sites have a number of options available; those areas with fewer resources and/or more sites have few options. The more precise and informative approaches inevitably take more time and are more costly. Therefore, a fundamental decision about funding priorities must be made.

Once this decision has been made, the final question is, "Of those approaches that I can afford, which will best meet my needs?" Review the pros and cons of each approach described below in the context of the types of information needed and the types of impact of most importance. Select a technique that maximizes accuracy, precision, sensitivity, and the amount and quality of information (criteria that will be discussed below) for those types of impact and information of most importance. If information needs cannot be met with available funds, more funds should be sought. Many monitoring funds have been wasted because the information collected is inadequate (often reflecting limited available funds).

Evaluation Criteria

In order to evaluate alternative approaches, evaluation criteria are needed. All acceptable systems must have several basic features. As was mentioned before, a census of sites is vastly preferable to a sample of sites. Without a census, there is no information on number of campsites. It is also necessary for any system to be set up in such a way that the same sites can be relocated at a later date. Finally, a system will be of little use if it cannot identify change in the most important impact parameters.

Much of the difference between acceptable systems is in their relative accuracy and precision. Accuracy describes how close an estimate is to a true value; precision describes how close several estimates are to each other, regardless of how close they are to the true value. Using a dartboard as an analogy, accuracy would be measured by the proximity of the darts to the bull's-eye. Precision would be measured by the proximity of the darts to each other, regardless of how close they were to the bull's-eye. Accuracy is important because we want to assess the current situation for campsites. We want a system that will tell us as accurately as possible, for the most important parameters, how much impact has occurred. Precision is important because we want to identify trends over time. If techniques are imprecise we will not be able to distinguish real changes from separate imprecise estimates of the same value. To monitor trends, precision is more important than accuracy.

The quality of the information collected is influenced by the scale of measurement—whether nominal, ordinal, or interval (Schuster and Zuuring 1986). Nominal measures involve placing observations in categories that do not imply order. An example is noting whether a campsite is located in a lodgepole pine forest, a Douglas-fir forest, or

a fescue grassland. Ordinal measures place observations in categories that do imply a relative order, but there is no information about the distance between observations or categories. An example is noting whether trash on the site is absent, evident, or abundant. We know that sites with abundant trash have received more impact than those on which trash is evident, but we do not know how different they are. Interval measures do provide information on the difference between two observations. For example, a site with 25 pounds of trash has 10 pounds more than a site with 15 pounds. Not only do we know which site is more impacted, we also know how much more impacted it is. Clearly, the amount of information generated by interval measures exceeds that of ordinal measures which, in turn, exceeds that of nominal measures. Another advantage of interval measures, as will be discussed later, is that they can be combined into synthetic summary indexes of impact. Although such indexes have frequently been constructed from ordinal measures (Cole 1983a; Parsons and MacLeod 1980), this procedure is mathematically inappropriate.

Sensitivity, another important criterion, describes how large a change must be for it to be identified confidently as a change. Sensitivity is dependent on both precision and quality of information. High sensitivity requires both precise measurements and either interval measures or ordinal measures in narrow classes. High sensitivity is desirable because it permits the identification of subtle changes.

Another important criterion is amount of information. Obviously, a system that generates information on a number of different types of impact is preferable to one that collects just one bit of information, as long as both the quality and importance of the information are similar. Sometimes information is collected on several parameters, but the information is combined in a single index. Unless information on each parameter can be disaggregated, such an approach loses all but a single bit of information.

The final criterion, which unfortunately is often the most important, is cost. Although it is possible to design low-cost systems that meet some of our criteria for a high-quality monitoring system, those that meet all of our criteria are the most costly.

As a final important note, the techniques described below were developed for a variety of purposes. Some were intended as monitoring systems; others were not. Those systems that do not rate highly in this critical review of each as the basis for a monitoring system are not necessarily "bad." They are described here because they have merits; unfortunately, all systems also have drawbacks. The important thing is to understand each alternative's pros and cons and to choose and modify a system that will closely meet specified needs. That is precisely why this first step of evaluating system needs is so important.

Evaluations of the monitoring systems described below are summarized in table 1.

Photographic Techniques

Some of the earliest attempts at monitoring relied primarily on photographic techniques. Magill and Twiss (1965), for example, describe how repeated photographs from permanent camera points can be used to detect changes in wildland resources, including campsites. The attraction of photography is that subjectivity can be reduced; consequently, precision should be high. The fatal flaw in most systems based entirely on photography is that the most basic assumption—that the most important types of impact will be monitored—is seldom met. Surprisingly few types of impact can be accurately evaluated in photographs, and essentially none of them can be assigned an interval level rating. Moreover, contrary to popular belief, photographs can lie. Photographs taken at different times of the day, under different lighting conditions, with different films, cameras, and lenses, or from slightly different vantage points can give misleading impressions.

Table 1—Strengths and weaknesses of alternative systems for monitoring campsites

	Evaluation criteria					
Monitoring system	Accuracy	Precision	Scale of measurement	Sensitivity	Amount of information	Cost
Photopoints (A)[1]	Low	High	—	Low	Mod. low	Mod. low
Condition class estimates						
Frissell (B)	Mod.	High	Ordinal	Mod. low	Low	Low
Parsons/MacLeod (C)	Mod. high	Mod. high	Ordinal	Mod. low	Low	Low
Permanent measures						
Cole (D)	High	High	Interval	High	High	High
Stohlgren/Parsons (E)	High	High	Interval	High	High	High
Nonpermanent measures						
Schreiner/Moorhead (F)	Mod. high	Mod.	Interval	Mod.	Mod. low	Mod.
Bratton (G)	Mod.	Mod. low	Interval	Mod.	Mod.	Mod. high
Cole (H)	Mod. high	Mod.	Ordinal	Mod.	High	Mod. low
Kitchell/Connor (I)	Mod. high	Mod.	Ordinal	Mod.	High	Mod. low
Marion (J)	Mod. high	Mod. low	Interval	Mod.	Mod. high	Mod. low

[1]Letters in parentheses refer to the appendix that provides a detailed description of each monitoring system.

In conclusion, although the accuracy and precision of photographs can be high, this is not always the case and accuracy and precision are irrelevant if important types of impact cannot be monitored. Sensitivity is low in most cases, as is the amount of information collected. Two reviews of available photographic techniques have concluded, consequently, that photographs should enhance but not replace the field measurements that are the foundation of most monitoring programs (Brewer and Berrier 1984; Cole 1983a).

Photographs can play several extremely important roles, however. They can be an indispensable means of determining if you are on the correct site when returning to reexamine a site. For relocational purposes, it is helpful to include in the photograph unusual landmarks or features likely to be around for a long time. Photographs are also an important tool for teaching evaluators to make consistent judgments when monitoring sites. This will be described in detail in step 4—documentation and training.

Photographs can also be a useful way to illustrate changes documented with field measurements. This can increase the effectiveness of written documents and presentations in communicating information on conditions and trends. Consequently, it is a good idea to take periodic photographs from permanent photopoints on a sample of sites. The sample should include as wide a range of situations (impact levels, types of impact, environments, and so forth) as possible. Guidance on establishing permanent photopoints can be found in Magill and Twiss (1965), Brewer and Berrier (1984), and in appendix A.

Condition Class Estimates

These systems involve assigning each campsite to a condition class category based on defined levels and/or types of impact. The presence, absence, or degree of change in certain critical parameters is quickly noted and forms the basis for an impact rating, usually between 1 and 5. Such systems can provide relatively accurate and precise estimates of overall impact. Sensitivity is low to moderate, depending on the number of categories that are defined. Sensitivity is higher when more classes are recognized, but this reduces precision because it increases the likelihood of differences of opinion about which class a site should be assigned to. The critical limitation of this technique, however, is that only one bit of information is provided and this information is only of an ordinal level. The only information that can be gleaned from such systems is the relative overall impact level on each site and whether conditions have improved or deteriorated enough, over time, to assign the site to another class. Information about specific types of impact and trends in specific impacts is lacking.

These systems are a good choice for areas with little funding per site. Only a few minutes are needed to locate each site on a map and record its condition class. This provides a gross estimate of impact levels and distribution. Such estimates are likely to be acceptably accurate and precise without spending much time on each site.

Two examples of condition class systems will be presented. The first example is the system proposed by Frissell (1978), based on his experience in the Boundary Waters Canoe Area Wilderness and in what is now the Lee Metcalf Wilderness. This system consists of descriptions of five condition states based on extent of vegetation loss, mineral soil exposure, tree root exposure, erosion, and tree mortality. Frissell's classes are as follows:

1. "Ground vegetation flattened but not permanently injured. Minimal physical change except for possibly a simple rock fireplace."
2. "Ground vegetation worn away around fireplace or center of activity."
3. "Ground vegetation lost on most of the site, but humus and litter still present in all but a few areas."
4. "Bare mineral soil obvious. Tree roots exposed on the surface."
5. "Soil erosion obvious. Trees reduced in vigor and dead."

Each campsite is simply assigned to the class that most accurately describes the condition of the site.

One problem with this system occurs when sites do not meet all of the criteria of any single class. For example, it is not uncommon for sites to have extensive tree root exposure (class 4), but retain litter and humus in all but a few places (class 3). This problem can be handled by assigning the site a value equal to the midpoint of two classes—for example, 3.5 in the example just described. Having done this, however, it is not possible to tell whether a 3.5 site has root exposure but little mineral soil or abundant soil exposure but no root exposure. In the Boundary Waters Canoe Area Wilderness, Marion (1986) found sites that fit all five condition classes, as well as each of the four midpoints between classes.

Another alternative would be to reword the definitions in such a way that if either of several conditions were found, the site would be assigned to that class. For example, the definition of class 4 could be changed to "Bare mineral soil obvious or tree roots exposed on the surface." If either of these conditions occurs, the site is assigned to class 4.

The problems that result from a combination of moderately low sensitivity and the provision of only one bit of information are more serious. In a study of campsites in Eagle Cap Wilderness, 71 percent of the sites examined were condition class 4 sites, despite considerable variability in site conditions, amount of impact, and amount of use (Cole 1982). In a study of a wide range of campsites in the Boundary Waters Canoe Area Wilderness, Marion (1986) assigned about two-thirds of all sites to classes between 2 and 3. Moreover, dramatic changes in condition must occur before they will be reflected in a change in condition class. Over a 5-year period, only one of the 22 Eagle Cap sites changed an entire condition class.

A final problem is that, while Frissell's system works well in coniferous forests with conspicuous ground cover vegetation and thick organic horizons, it does not apply to many other environments, such as areas above timberline, grasslands, or deserts. This problem can be dealt with by developing similar class definitions that are adapted to these other environments. In wilderness areas with a variety of structurally distinctive environments, however, it may be impossible to develop readily comparable rating systems that work well in all environments.

This problem—of a system working well in some environments but not in others—is avoided with a condition class system that was devised by Parsons and MacLeod (1980) for use in Sequoia and Kings Canyon National Parks. They also recognize five condition classes, in this case based on eight criteria: density of vegetation, composition of vegetation, total area of the campsite, barren core area, campsite development, litter and duff, social trails, and tree mutilations. For each of these criteria, the site is assigned a rating from 1 to 5, based on descriptions (see appendix C for more detail). The condition class is then the closest integer, between 1 and 5, to the mean of these ratings. With practice, the evaluator can simply look at a site and assign it to a condition class without going through the process of assigning a rating to each criterion and determining a mean. This results in a system quite similar to that of Frissell in which "a class one campsite would usually be no more than a small sleep site and possibly a fire ring, with little or no vegetative change or trampling evident," while "a class five site would be a large, heavily used barren area" (Parsons and MacLeod 1980).

Compared with Frissell's (1978) system, this approach avoids the problem of sites not fitting into a single class. By including more impact parameters, as well as a range of conditions for each parameter, the distribution of sites across the range of condition class values is more equitable. The Parsons and MacLeod (1980) system is probably less precise than the Frissell system because more decisions (one for each criterion) must be made before a class rating can be assigned. Moreover, the practice of assigning a class rating without evaluating each criterion, once considerable experience with the system has been gained, also increases the likelihood of bias and loss of precision.

The Parsons and MacLeod (1980) system is a more accurate predictor of impact, however. Two studies have correlated condition class ratings with impact indexes derived from careful measurements on campsites. High correlations were found in both the Eagle Cap (Cole 1982) and Boundary Waters Canoe Area Wildernesses (Marion 1986), indicating that both systems accurately portray impact levels on campsites. In the latter wilderness, where both the Frissell system and a modification of the Parsons and MacLeod system were compared, the correlation coefficient was considerably higher for the Parsons and MacLeod method.

Such systems clearly achieve some of the goals of an inventory and monitoring system and can be a good choice in places with severe funding constraints—a common situation in wilderness and backcountry. They provide relatively accurate and precise information on (1) the number and distribution of sites, (2) changes in the number and distribution of sites, (3) relative impact levels in different portions of the wilderness, and (4) relative impact levels for individual sites. Their value in monitoring changes in the condition of individual sites is more limited. Moderately low sensitivity and low information content mean that only sizable changes in overall condition can be detected and no information is available on what types of impact are particularly severe or either deteriorating or improving.

This means that monitoring information cannot be used to develop campsite management programs that target specific types of impact in particular places. Problem areas can be flagged, but it will be up to managers to guess how they have changed and to decide, on the basis of field examinations, what should be done.

Two other problems are of a more technical nature. One problem is that use of condition class systems locks managers into the current set of impact parameters and their implicit equal weighting. If managers change their opinions on the parameters to be used or their relative importance, they will raise serious problems. If they redefine the condition classes, the information generated will no longer be comparable to previous ratings. On the other hand, if they continue to use definitions that are no longer appropriate, the survey may be largely irrelevant.

The second problem is confined to the Parsons and MacLeod (1980) system. It results from performing the mathematically improper procedure of calculating the mean of several ordinal ratings. Because the intervals between ordinal ratings are unknown—they undoubtedly differ both within and between criteria—a mean cannot be readily interpreted (Schuster and Zuuring 1986). Although a class 5 site would clearly be more highly impacted than a class 1 site, certain class 4 sites may not be more impacted than class 3 sites. Although the high correlations between these inappropriate means and interval scale measurements suggest that a site with a high mean is usually highly impacted, use of this improper procedure interjects potential for misleading results.

Measurements on Permanent Sampling Units

A very different approach is to take detailed measurements of a number of impact parameters on permanently located sampling units, usually quadrats, transects, or the entire campsite. Periodic repeat measures of such parameters as vegetation cover and composition, mineral soil cover, and bulk density or number of damaged trees can provide highly accurate and precise measures of impact. If designed properly, such data are highly sensitive and the amount of information is high because many parameters can be examined and interval measures can be obtained. Such systems rate highest in all evaluation criteria with the exception of cost. Measurements of this type usually require several people spending several hours on each site, and additional office time is required for data reduction.

Because costs are so high, it is unlikely that measurement systems based on permanent sampling units can do more than sample sites. Therefore, these techniques are more common in research studies than in a true monitoring program. Given a relatively small number of sites, measurements of this type could form the basis for a monitoring program that provides a large quantity of accurate and precise information. More commonly, detailed measurements on a sample of sites might be used to supplement less precise rapid estimates taken on all sites.

Two alternative designs will be described here. The first design was initially used in a study of changes on a sample of 26 campsites in the Eagle Cap Wilderness initiated in 1979 (Cole 1982, 1986a). It has subsequently been used, in modified form, on samples of campsites in various areas, including the Bob Marshall Wilderness (Cole 1983b), Grand Canyon National Park (Cole 1986b), and Delaware Water Gap National Recreation Area (Cole and Marion 1988). It has proven to be a useful design for describing both current impact levels and changes over time. A more detailed description of the procedure is included in appendix D.

The procedure calls for a large nail to be buried near the center of each campsite. For subsequent monitoring purposes, this nail can be found with a lightweight pin locator (a type of metal detector). From this point, the distance to the edge of the obviously disturbed part of the site is measured in 16 directions. The polygon enclosed by straight lines connecting transect end points defines the camp area, within which damage to trees and density of tree reproduction (number of stems/acre) is evaluated.

Four transects between the center point and campsite boundary are established at right angles to each other. Nails are buried at the end of each transect to facilitate reestablishment of each transect. Approximately fifteen 3.3- by 3.3-ft (1- by 1-m) quadrats are located along these transects. The number of quadrats on each transect is proportional to the relative length of each transect. The distance between successive quadrats decreases with distance from the center point so that there is less tendency to oversample the center of the site.

The canopy cover of total ground cover vegetation, exposed mineral soil, and each plant species is estimated for each quadrat. Measures of the depth of organic horizons and the penetration resistance of the soil are also taken in each quadrat. Means for each of these parameters are then calculated for the campsite as a whole. Four soil samples are taken in the central part of the campsite to obtain measures of soil bulk density, moisture content, and chemical composition. Finally, four measures of water infiltration rate are taken close to these soil samples.

While these measures provide information about the condition of the campsite, they do not indicate how much change has occurred on the site. For example, a site with a vegetation cover of 50 percent may be perfectly natural or it could have lost as much as half of its vegetation cover. To obtain estimates of how much change has occurred on campsites, similar measures are taken on environmentally similar undisturbed sites (controls) in the vicinity.

Selection of suitable controls demands great care. The idea is to select a site that you think the campsite would have looked like before it was camped on. The best controls will be similar to the campsite in tree canopy density, rockiness, and slope, and have ground cover species similar to those surviving in protected places on the campsite. It is also desirable to find a control as close to the campsite as possible.

Once selected, the control must be referenced to the campsite so it can be relocated. Then a nail should be buried at the site center. The most efficient size for a control will vary with environmental heterogeneity; controls should be larger in more heterogeneous environments. In the Eagle Cap, circular controls of 1,000 to 2,000 ft^2 (100 to 200 m^2) were used.

In order to characterize amount of impact, campsite conditions are compared to those on controls. For example, the difference between vegetation cover on the campsite and the control provides an estimate of how much vegetation has been lost from the campsite. To characterize change over time, one can either examine the difference between campsite conditions obtained during successive observation periods or examine the change in the amount of impact (the campsite/control comparison). For example, on Eagle Cap sites receiving moderate levels of use, vegetation cover decreased from 6.1 percent in 1979 to 5.7 percent in 1984; vegetation loss (the difference between cover on campsites and controls, expressed as a proportion of cover on controls) increased from 75 percent in 1979 to 79 percent in 1984 (Cole 1986a).

A different design was employed to follow change on closed campsites in Sequoia National Park (Stohlgren and Parsons 1986). Refer to appendix E for more detail. On each campsite, a 32.8- by 32.8-ft (10- by 10-m) study area is identified. Permanent stakes are placed around the perimeter at 3.3-ft (1 m) intervals. Buried nails at each of the four corners can serve to permit relocation of these stakes. String is set up between stakes to establish a grid of 10.8-ft^2 (1-m^2) squares. Each quarter of each square is then subjectively stratified into core, intermediate, or periphery. Core areas are the most denuded places, located close to the center of the site. Intermediate areas exhibit obvious impact, but have more vegetation cover, less litter and duff pulverization, and some pockets of intact surface sod. Periphery areas, essentially controls, appear to be unimpacted. Of all the quarter squares—each 2.7 ft^2 (0.25 m^2) —that fall entirely in one of these strata, five to 10 are randomly selected. In each, canopy cover of each plant species is estimated and bulk density, soil penetration resistance, litter accumulation, soil moisture, and soil chemistry are measured.

Both the Eagle Cap (Cole 1982) and Sequoia (Stohlgren and Parsons 1986) systems will provide quite precise measures of change because each employs replicable measures on plots that can be readily relocated. There can still be measurement error, however, if for example, estimates of vegetation cover tend to be high one year and low the next year. If campsites are compared with controls, this problem should be reduced because the same bias would be applied to controls and, therefore, canceled out when the differences between campsite and control are calculated.

Levels of accuracy and information provided are likely to be very different depending on which of these techniques is used. The Eagle Cap technique provides only one measure of each type of impact, characteristic of the entire campsite. The Sequoia technique recognizes that conditions within the campsite are not homogeneous and provides one measure characteristic of the most highly impacted parts of the site and another measure for the parts of the site that are intermediate in impact. Depending on information needs, this added information provided by the Sequoia technique can be useful or it can add unnecessary complexity. It provides a more accurate picture

of intrasite variability but does not provide a single summary measure for the entire site.

Several features of the Sequoia technique reduce its accuracy, relative to the Eagle Cap technique. First, measurements are taken on only a very small proportion of the site. Measurements on the core and intermediate areas are taken in a total area of no more than 50 ft^2 (5 m^2) compared to 150 ft^2 (15 m^2) on Eagle Cap sites. Moreover, on most sites much of the campsite is likely to be outside of the 1,076-ft^2 (100-m^2) area that was sampled. (The median camp area in the Eagle Cap was almost twice this size.) Second, using periphery measures as control values can be misleading. Areas less than 16 feet (5m) from the center of the site are likely to either be quite disturbed or, if they have not been disturbed, they are likely to be environmentally distinct from the campsite proper (for example, under a tree or among rocks).

Both the Eagle Cap and Sequoia techniques provide useful, precise, and sensitive information on change to the campsite. As Stohlgren and Parsons (1986) have shown, the added information provided by stratifying the campsite into core and intermediate zones may be preferable for examining recovery of closed sites because intermediate parts of the site recover more rapidly than core parts. But the Eagle Cap technique appears more likely to provide accurate estimates of how much impact has occurred to the site as a whole because the entire campsite is included in the sample, the size of the area sampled is larger, and controls are likely to be more representative. It appears that it should also require less time and therefore should be less costly.

Other variations on these techniques can and have been tried (Echelberger 1971; LaPage 1967; Leonard and others 1983; Magill 1970; Merriam and others 1973). The most useful ones will provide accurate measures of how much impact has occurred to the campsite and be designed to facilitate precise replication of measurements on the same sampling units. It is the care that goes into precise replication that takes so much time and makes these techniques costly.

Measurements and Estimates Without Permanent Sampling Units

With the preceding techniques much time is spent establishing permanent sampling units on campsites. Several alternative systems take measurements and estimates of impact on campsites without establishing permanent plots. Schreiner and Moorhead (1979) developed such a system in the early 1970's for use in Olympic National Park. They measured the distance to the first live plant along eight transects radiating from the center of the site. The average distance was used as the radius of a circle to calculate bare ground area. They also counted the number of access trails radiating from the site to water, the main trail, or other campsites, as well as the number of places that had been trampled heavily by horses, within 100 feet of the site.

In a study of campsites in Eagle Cap Wilderness, the bare radius proved to be highly correlated with a synthetic index of change in a number of impact parameters (Cole 1982). This suggests that it does provide an accurate indicator of overall impact. Precision is more of a problem, however. Centerpoints were not permanently marked and slight shifts in the center resulted in sizable differences in bare radius and area. With a large measurement error, only sizable changes in bare radius or area can be interpreted as definite changes in impact; consequently, sensitivity is only moderate. Only three types of information were collected. Although interval scale measures were taken, the advantage of interval measures over ordinal measures is reduced by the sizable measurement error. Costs are moderately low because these techniques require little time on the campsite. One variation of this system required that a scale map be drawn; this required considerable time, making it costly as well.

Another system based on areal measures was used on backcountry campsites in Great Smoky Mountains National Park (Bratton and others 1978). In this system, the lengths and widths of various types of impact were measured. The types of disturbance measured were bare rock, mud, slope erosion, and bare soil (all of which could be combined in a measure of total bare soil), leaf litter (areas in which litter remained but all vegetation was lost), and trampled vegetation. In addition, trash, tree damage, and firewood clearing were quantified by measuring out along at least two axes to where these disturbances ceased and then calculating the area involved.

The data generated by this system are only moderately accurate. As Bratton and others (1978) noted, defining all of these disturbances as rectangles overestimates damage. Moreover, the only data provided are areal measures of impact. No data can be generated, for example, on how many trees have been damaged or how much vegetation has been lost. In addition, the lack of controls makes it impossible to estimate how different campsites are from undisturbed areas.

The precision level of this system is likely to be moderately low. No permanent center points or transects were established. In future remeasurements, new center points and axes will be selected. The resultant areal measurements are likely to be very different, even if no change in impact occurs. Given the sizable measurement error, differences in areal measures would have to also be sizable before they could be interpreted as definitive evidence of a change; therefore, sensitivity is only moderate. Compared to the Schreiner/Moorhead technique, information is collected on more types of impact, although many important types (such as tree damage, soil compaction, access trails, or change in vegetation composition) are left out. Again the value of interval scale data is reduced by the sizable measurement error. Finally, it appears that this technique would be quite time consuming, suggesting that the cost of implementation would be moderately high.

In evaluating these systems in relation to the permanent plot approach, the question that arises is whether or not the lower cost is worth the loss of precision and sensitivity that comes with not establishing permanent sampling units. If the cost savings is worthwhile, would it be worthwhile to cut costs even further by relying less on detailed measurements?

Much of the progress in recent years has come in the search for techniques that will provide a suitable compromise between costly measurement systems and systems that provide little specific information. The nagging problem with all of these techniques is their relatively low precision levels. How can one rapidly estimate impact parameters while still keeping measurement error small?

A series of estimation systems have been developed that draw heavily on earlier ideas, particularly some of those advanced by Schreiner and Moorhead (1979) and Parsons and MacLeod (1980). The major differences have been attempts to (1) collect information on more parameters than Schreiner and Moorhead did, (2) avoid the problem inherent to the Parsons and MacLeod system of not being able to disaggregate data on each parameter, and (3) maximize precision levels but use interval measures where possible. Progress has been made, but problems remain. Despite these problems, I believe that once refined, these systems will provide the best compromise for the budgets of most backcountry areas.

A system developed by Cole (1983a) is patterned closely after that of Parsons and MacLeod (1980). The most important change is that each parameter is recorded separately in the field. While this adds a few minutes to the time it takes to complete the form—requiring an average of about 10 to 15 minutes for experienced evaluators to measure a site—it increases the amount of available information greatly. Other changes include (1) use of more precisely defined techniques for evaluating change in vegetation density and litter and duff cover, (2) deletion of the vegetation composition parameter, (3) separation of the mutilation parameter into a count of both trees that have trunk damage and trees with exposed roots, and (4) separation of campsite development into both development and cleanliness parameters. See appendix H for a detailed description of the procedure.

The accuracy of this system was evaluated by Marion (1986) and found to be moderately high, as the Parsons and MacLeod (1980) system was. Precision is less high, however; it is only moderate. This results from the fact that many more judgments must be made in the field. The fact that categories are broad suggests that, with training, judgments should be acceptably precise, but differences of opinion will be more common than with condition class systems or measurements taken on permanent plots.

The primary advantage of the system is the large amount of information that can be collected in a short period of time. Of all systems, this produced the most information per unit of cost. Although the system initially consisted entirely of ordinal estimates, it was eventually modified to consist of interval estimates that were recorded and then used to assign each parameter an ordinal ranking. This provides even more information, although the precision of the interval estimates must be questioned. Measurement error needs to be minimized (see step 4) and quantified (see step 3).

With all of this information, it is clearly advantageous to assign a single summary impact rating (essentially a condition class) to each site. This is done by multiplying each parameter by a weight assigned to each parameter (more important types of impact are assigned higher weights). These products are then summed to provide a summary rating. Dividing these ratings into, for example, five classes will produce five condition classes. Changes over time in summary rating can be followed, as can changes in the individual impact parameters.

As was the case with the Parsons and MacLeod (1980) system, this procedure improperly sums a series of ordinal rankings. This makes the summary ratings difficult to interpret. Widely divergent ratings should accurately reflect the relative impact of different sites; however, interpretations of even relative differences between sites with proximate summary ratings are suspect. A site with a rating of 50 may be less impacted than a site with a rating of 47, for example. This merely reinforces the major problem with this type of system—a precision level that is lower than desirable, and a paucity of information on just how low precision is.

Despite these problems, modifications and similar systems have been developed for use in such widely divergent situations as canoe campsites in the Boundary Waters Canoe Area Wilderness and the readily accessible Delaware Water Gap National Recreation Area (see appendix J), sites on whitewater rivers such as the Middle Fork of the Salmon and Colorado Rivers, and backpacker sites in the deserts of Canyonlands (see appendix I) and Grand Canyon, as well as sites in mountainous areas similar to those where such systems were first developed. Although parameters and procedures differ (these will be described more fully, with examples, in step 2), the approach of making rapid estimates of a number of parameters remains consistent.

At the Delaware Water Gap, however, problems with low precision have led managers to base as many methods on counts and measurements as possible. As methods for the area have developed, managers have felt it necessary to spend more time and to use more precise techniques (see appendix J).

Time Estimates

Clearly, the time required to use any of these approaches will be highly variable. Nevertheless, it seems important to provide some general estimates of time required. Photopoint systems might take one person about 30 to 60 minutes per site, depending on the number of photographs to be taken. The condition class systems take one person from 3 to 5 minutes per site. The systems of measurements on permanent plots usually take two people between 1 and 3 hours per site, depending on the parameters to be measured. The measurement and estimation systems without permanent plots are highly variable; the Cole (1983a) system might take one person 10 to 15 minutes per site, while a system similar to that used by Bratton and others (1978) might take several people several hours per site.

Research Needs

The primary research need is to refine rapid estimation techniques that provide information on a number of separate impact parameters but do not take very much time per site. The problems with these techniques are low

precision levels, uncertain measurement errors, and use of inappropriate summary impact ratings. Some means of increasing precision levels are described in steps 2, 3, and 4, steps that involve the development, testing, and documentation of specific procedures. Research needs to go further toward identifying the most precise estimation procedures and suggesting means of maximizing precision. The issue of measurement error and its estimation is dealt with in step 4. Very little evaluation of error has been conducted, however; more research is needed on this subject. Several appropriate ways to calculate summary impact ratings are described in step 2; more work on this subject would also be valuable.

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STEP 2. DECIDE ON IMPACT PARAMETERS AND EVALUATION PROCEDURES

The next step is to decide what to monitor and how to conduct the monitoring. At this point a monitoring approach should already have been selected and some of the most important types of impact should have been identified. Clearly it is most important to monitor the impact parameters considered to be the most critical.

Decision Making

If you have selected a photopoint system, step 2 can be skipped, although it might be worth reading for hints on what to photograph. Details on how to establish a photopoint system are included in appendix A. Some of the discussion in step 4—documentation—is also relevant to photopoint systems.

For all of the other approaches, decisions must be made about which impacts are most critical and, within the constraints of the three basic types of systems—condition class, measurements with permanent plots, and measurements or estimates without permanent plots—how each type of impact should be monitored. While it is not necessary or even desirable to collect information on all possible types of impact, it would be worthwhile to collect information on types of impact that require different management strategies. For example, because the size of the site and number of access trails might be controlled with site management techniques that are very different from the behavioral controls needed to deal with tree damage, it would be worthwhile to assess each of these different types of impact.

If a condition class system was selected in step 1, it is time to select the impact parameters to form the basis for the rating. The parameters Frissell (1978) used are well suited to forested areas with abundant understory vegetation and thick soil organic horizons; other parameters will have to be selected in very different environments, such as those above timberline, in grasslands, or in the desert. Considerable thought and creativity need to go into developing a system of this type. A sequence of progressive impact stages must be described, followed by definitions of each stage in terms of the most important impact parameters. It is important that categories are mutually exclusive so that all sites can be assigned to one and only one category.

It is a simpler matter to develop a condition class system similar to that described by Parsons and MacLeod (1980). Each type of impact is described separately so that the relationships between different types of impact need not be understood. Moreover, the large number of

parameters examined makes it likely that many different types of environment can be evaluated with this technique. Decisions must be made about which parameters to use, how each parameter will be evaluated, and how a summary rating will be derived. Assessment techniques for impact parameters and means of deriving a summary rating are described below.

If an approach similar to that of Parsons and MacLeod (1980) is selected, however, it is worthwhile to take the little additional effort to separately record information on each parameter. This increases the amount of information available many times. Although this requires more time, the added time is usually minor in comparison to the time spent in transportation. Separately recording each parameter should also increase the objectivity and precision of summary ratings because the procedure of deciding on a rating is not shortcut.

This simple change—recording each parameter separately—results in the type of system described by Cole (1983a, 1984) and used in such places as the Bob Marshall, Canyonlands (Kitchell and Connor 1984), and the Boundary Waters Canoe Area. As with the Parsons and MacLeod (1980) system, parameters and evaluation procedures can be selected from the following examples (although other parameters or procedures could certainly be developed). Generally, with these systems, each individual estimate does not require much time. Therefore, once on a site, it is usually worth collecting information on as many important parameters as possible.

If a system based on measurements in permanent plots was selected in step 1, each measurement can be quite time consuming, so it is more important to select only the most critical parameters. Much of the requisite time on the site, however, is involved in establishing and relocating permanent sampling units. Given this investment of time, it would be unfortunate to not collect information on as many important parameters as is feasible.

Impact Parameter Descriptions

In the following sections, impact parameters that have been included in monitoring systems will be described. A final section will discuss the derivation of summary ratings and condition class ratings. More detail on some of these procedures can be found in the appendixes.

Campsite Area—One of the most obvious measures of impact is the area affected by camping. Assuming a similar level of vegetation loss, soil compaction, and so forth, larger campsites can be considered to be more heavily impacted. For example, the quantity of vegetation lost from a 200-ft^2 campsite that has lost 50 percent of its cover is twice that of a 100-ft^2 site that has also lost 50 percent of its cover. In addition, size of the campsite is one of the most useful parameters for distinguishing between lightly and heavily used sites and it is more likely than most parameters to change over time (see, for example, Cole 1982, 1986a; Marion and Merriam 1985).

Although it is an obvious impact parameter, camp area can be difficult to measure accurately or precisely. Two problems contribute to inaccuracy. First, it can be difficult to define the edge of the site. In areas of dense fragile vegetation, a boundary can be consistently defined by a contrast between untrampled vegetation and trampled vegetation or bare ground. Where vegetation is sparse, boundary definition can be difficult unless obvious disturbance of organic horizons can be used. In areas of rock outcrops, sand, and gravel, or in resistant vegetation such as dry grassland or meadows, it can be virtually impossible to define a nonarbitrary campsite boundary.

Even where a boundary can be defined, another problem stems from the difficulty of measuring the area of an irregular figure. If a site is a perfect circle or rectangle, its area can be measured precisely and quickly. Because this is never the case, accurate and precise estimates of the area of sites that differ greatly from simple geometrical shapes is time consuming.

The method that Cole (1982) used to monitor changes on sites in Eagle Cap is relatively precise. A permanent center point is used. From this point, 16 radial transects are extended out to the edge of the site. The distances from center point to boundary are plotted on radial maps and then the area of the site is determined with a polar planimeter. Accuracy increases with the number of transects; precision is increased by using a permanent center point. The Schreiner and Moorhead (1979) system, on which the Eagle Cap technique was based, is an example of a less accurate and precise system. It does not use a permanent center point, it uses only eight transects, and area was calculated on the basis of a mean radius—an assumption that would only produce an accurate result if the site was circular.

Cole's (1982) technique requires about 90 staff-minutes per site. The Schreiner/Moorhead technique might require only about 25 staff-minutes per site because it is not necessary to find the buried center point and it is not necessary to map the transect end points or use the planimeter.

If campsites are relatively regular in shape (without many peninsulas and islands that are not trampled), Cole's technique can be used to measure area, without plotting transects or using the planimeter. The 16 radial transects define two sides of 16 triangles; a straight line between transect end points is the third side. The area of the campsite is the sum of the area of the triangles, each of which can be calculated as 0.5 times the sine of the angle (0.383 for the 22.5-degree angles created by 16 transects) times the product of the two transect lengths. Any number of transects could be used, although the appropriate angle would vary. Use of this procedure would reduce time requisites considerably. Managers at Delaware Water Gap plan to use this technique in an effort to obtain more precise areal estimates than they have in the past (see appendix J).

More rapid areal estimates are also possible. If the area can be considered to approximate either a circle or a rectangle, or a combination of simple geometric forms, a radius or lengths and widths can be paced off. Using the appropriate formulas, areas can be calculated quickly. While these areal estimates may not be very precise, they can be completed in a few minutes by one person. Moreover, in places where it is difficult to define a nonarbitrary boundary, these estimates may be as precise as the most careful measurements.

If rapid estimates of area are used, it is important to invest considerable time in training and in deriving a rough estimate of measurement error. This measurement error can be used to establish confidence limits around an estimate. If future estimates are not beyond these limits, the interpretation should be that there is a high likelihood that no real change in area has occurred. More discussion of measurement error, its importance and use will be presented in step 3.

Another way to both reduce estimation times and handle problems with precision is to merely assign each site to a class based on a range of areas. For example, in the Bob Marshall Wilderness (Cole 1984), three classes were defined: 0-500 ft^2 (0-46 m^2); 501-2,000 ft^2 (47-186 m^2); and >2,000 ft^2 (>186 m^2). The system used in Sequoia and Kings Canyon National Parks recognized five classes: 0-20 ft^2 (0-2 m^2); 21-100 ft^2 (3-9 m^2); 101-500 ft^2 (10-46 m^2); 501-1,000 ft^2 (47-93 m^2); and >1,000 ft^2 (>93 m^2). With experience, it is usually possible to assign a size class to many campsites without any pacing or measurement. As the number of classes increases, precision decreases—because the likelihood of assigning a site to the wrong class increases—but sensitivity increases. More classes are preferable, if relatively high precision can be maintained through training and calibration of evaluators. Ideally, classes should be as broad as the confidence interval around estimates, for whatever technique is used.

A final option, utilized in the Bob Marshall Wilderness (Cole 1984), is to estimate the area of the site and to then assign each site to a class, on the basis of this estimate. The ordinal class rating is used to compare the size of different sites or to evaluate change over time. The interval estimate is a help in interpreting change, particularly if estimates are close to the boundary of classes. For example, a change of one class is less meaningful if the original estimate was close to the boundary of the class assigned during a subsequent rating.

Although campsite area is an important measure of impact and has been monitored in most systems in use, its problems are considerable. Where defining nonarbitrary boundaries is difficult, it might be best to not measure area. Often there is a strong correlation between the devegetated area of the site and the total area of the site. Where devegetated area can be determined much more precisely than total area, it might be monitored instead. Across a variety of environments, however, devegetated area cannot be considered a surrogate for camp area. In general, the proportion of the camp that is devegetated should increase as vegetation fragility, amount of use, and roughness of the local environment increase.

Other problems with defining campsite area include how to handle separate sites that have grown together, satellite tent pads, and places offsite where stock have been tethered. The problem of intermingled sites is discussed in detail in step 5—field data collection procedures. Satellite sites and stock-holding areas either can be ignored (this reduces the accuracy of areal estimates of damage) or their area can be measured or estimated and then either reported separately or added to the total camp area. Problems can arise with deciding to which site one should assign a satellite site or stock holding area. One should avoid contaminating a precise estimate of camp area with an imprecise estimate of satellite area. If techniques with different precision levels are used, the two estimates should be kept separate.

Campsite Development—Another common item to address is the extent of development; that is, the number and elaborateness of either agency or user-built facilities such as fire pits, rings, grates, or places; seats; tables; shelters; and so on. The usual technique has been to record the presence or absence of each, with or without a count of the number of each type of facility. In addition, development classes have been suggested by Parsons and MacLeod (1980) and by Cole (1983a) (see appendix H). The difference between the two is primarily in the number of classes and that Cole chose to separate cleanliness aspects (such as amount of trash) from development.

The ability to quantify this parameter is limited. Several systems require a count of firepits. A rapid estimate system developed for the desert environment of Canyonlands National Park (Kitchell and Connor 1984) also records the number of rocks larger than 6 inches in diameter that have been moved either to create flatter tent pads or to construct tables or seats. This number is then used to assign the site to one of four classes for rock displacement.

Cleanliness—Cleanliness refers to trash, human waste, horse manure, and campfire remnants, particularly charcoal. Again, quantification is difficult. In a study of campsites along the New and Delaware Rivers, the number of 33-gallon trash bags of garbage found on each site and the number of separate piles of toilet paper, with or without feces, within 164 ft (50 m) of the center of the site were counted (Cole and Marion 1988). This did not effectively distinguish between clean sites and ones with a small amount of trash. Counts of number of trash items have been used—for example, in the Canyonlands system (Kitchell and Connor 1984)—but this fails to distinguish between large items, such as a tarp, and small items, such as a cigarette butt. For human waste, Kitchell and Connor (1984) count pieces of toilet paper and piles of feces and note the presence or absence of urine odor. Such estimates vary with the eyesight of the evaluator and the time spent searching.

Problems with quantification can be dealt with through classification. For backpacker sites, Kitchell and Connor (1984) suggest classes for trash (none, 1-3 pieces, 4-6 pieces, and >6 pieces), toilet paper (none, 1-2 pieces, 3-4 pieces, and >4 pieces), and feces (none, 1 pile, 2 piles, or >2 piles). They have different categories for sites used by visitors in four-wheel-drive vehicles and sites used by boaters. Cole's (1983a) system deals simultaneously with all aspects of cleanliness. Categories are: (1) no more than scattered charcoal from one firering; (2) remnants of more than one firering or some litter or horse manure; and (3) either some human waste evident or much litter or horse manure.

Cleanliness and extent of development can have a profound effect on visitors. For example, Lee (1975) found that cleanliness and development were the site conditions most critical to the enjoyment of visitors in the Yosemite backcountry. But they are not a lasting ecological impact on the land; they are easily removed. A strong argument

can be built for noting cleanliness and development but separating them from ecological impact parameters. Counts of facilities, including firepits and the number of places where fires have been built, seem worthwhile. The problems with quantification of trash and human waste suggest, however, that a system of classes (such as none, some, and abundant) provides as much information and as high a level of precision.

In a study of impacts on camping beaches in Glen Canyon National Recreation Area, Carothers and others (1984) developed techniques for quantifying trash and charcoal accumulation. Trash accumulation was established by counting, removing, and weighing all human trash within 16 ft (5 m) of a 49- to 164-ft (15- to 50-m) transect running through the center of each site. Sand discoloration was used as a measure of ash incorporation into the sand. A 50-mL surface sample of sand was collected in each of 10 quadrats located along the transect and passed through a sieve (mesh size 150 microns). These samples were then shaken 75 times against a circular disk of coarse Fisher Filter Paper. A discoloration index was then obtained by matching the color of the filter paper to colors obtained from a series of beach sands containing known charcoal-ash concentrations. The index ranged from 1 (sand with no ash or charcoal) to 16 (sand that contains 10 percent residue by volume). It might be possible to design a similar technique for use in environments other than sand beaches.

A unique parameter used at Canyonlands (Kitchell and Connor 1984) is the abundance of ants, flies, and rodents on and around campsites. The idea is that sites with more of these pests tend to be more highly impacted. Four classes were derived for backpacker sites from "no pests within 50 feet [15 m] of the site" to "greater than 1 ant colony; ants throughout site; numerous signs of rodents, tracks, burrows and nests within 20 feet [6 m] of site."

Damage to Overstory Trees—Most systems attempt to monitor the extent of damage to overstory trees on campsites. Some of the questions that need to be addressed include how many different types of damage to assess separately, whether or not to consider only trees within the campsite boundaries, at what height or diameter does a tree become an overstory tree, at what level of damage should a tree be considered damaged, how to deal with felled trees and stumps, and whether to provide an interval level count of trees or a damage classification. One problem in some situations is distinguishing recreational damage from "natural" damage.

In the Eagle Cap and Bob Marshall Wildernesses, Cole (1982, 1983b) counted all trees greater than 4.5 ft (140 cm) tall on the campsite, noting the extent of damage to each tree. The number and percentage of trees that had been felled or that had trunk scars or exposed roots was calculated. The number and percentage of trees with any damage was also noted.

Marion (1984; Marion and Merriam 1985) distinguished four levels of damage to standing trees: none (no tree damage other than from obviously natural causes); slight (nails, nail holes, small branches cut off or broken, small superficial trunk scars); moderate (large branches cut off or broken, trunk scars and mutilations that may be numerous but do not total more than 1 ft^2 [0.09 m^2] of area); or severe (trunk scars that total more than 1 ft^2 [0.09 m^2] or complete girdling of the tree). Each standing tree within the campsite boundaries was counted and classified according to damage level. In this system, trees with a diameter at breast height greater than 0.8 inch (2 cm) were considered to be trees. A damage index was calculated by multiplying the number of trees in the "none" category by 1 and the number of trees in the slight, moderate, and severe categories by 2, 3, and 4, respectively. These products were summed, and this sum was divided by the total number of trees. The index, which varies between 1 and 4, can be interpreted as the average damage to trees on the site. For example, an index of 2.5 suggests that the average tree is about halfway between slight and moderate damage. Felled trees were recorded separately, although they might, more appropriately, have been placed in a fifth damage class.

A similar classification of root exposure was as follows: none (no root exposure other than from obviously natural causes); slight (the tops of many of the major roots exposed or more severe exposure on only one or two major roots); moderate (the tops and sides of many of the major roots exposed or very severe exposure on only one or two major roots); and severe (the tops, sides and undersides of many of the major roots exposed). An index was calculated as for tree damage.

One problem with this approach is that many of the damaged trees are found offsite. Visitors usually tie their horses offsite, causing root exposure, or fell trees for firewood or tent poles offsite rather than onsite. Thus, a count of damaged trees onsite will usually vastly underestimate amount of damage. The problem with counting trees offsite is that different evaluators may go different distances from the site to search for damaged trees. This reduces precision.

Bratton and others (1978) quantified tree damage in terms of the maximum distance from the center of the site along at least two axes. This measure is difficult to interpret (for example, it says nothing about the proportion of damaged trees or the severity of damage) and is not likely to be very precise.

Other systems have assigned rankings to sites based on the extent of tree damage. With the Parsons and MacLeod (1980) system, the number of mutilations is counted, regardless of their nature or whether they occur on one or more trees. Highly obtrusive mutilations are distinguished from other mutilations. Categories are: none, 1-2; 3-5; 6-10, or 1-2 highly obtrusive; and >10 or >2 highly obtrusive mutilations. Apparently, only trees on the campsite are included, although this and the definition of a highly obtrusive mutilation is not included in their paper.

In the system developed for the Bob Marshall, Cole (1984) had evaluators count and record the number of trees that have been scarred or felled, as well as the number that have exposed roots that are obviously associated with the site being examined (regardless of whether they are onsite or not). Then sites are assigned to a class. For damage, the classes are: no more than broken lower branches, 1-8 scarred trees or 1-3 badly scarred or felled trees, and >8 scarred trees or >3 badly scarred or felled trees.

To be "badly-scarred," the surface area of scars must exceed 1 ft^2 (0.09 m^2). The classes for root exposure are: none, 1-6, and >6 trees with exposed roots.

There are problems with any means of evaluating tree damage. Confining the monitoring to the campsite itself increases precision, but reduces the accuracy of the estimate of impact. Perhaps the best compromise for a low-cost system would be to count trees both onsite and offsite, but only count trees with pronounced damage, such as those in the moderate and severe classes that Marion and Merriam (1985) define. Recording the number counted, as well as an impact class, also seems a useful compromise between the low-information classification option and the problem, with a count, of having the number appear more precise than it really is. Both can add to the interpretation.

Tree Reproduction—Loss of tree reproduction has been monitored using measurements on permanent plots, but I know of no examples of rapid estimates. The technique is to count reproduction—defined in the Eagle Cap (Cole 1982) as trees between 6 and 55 inches (15 and 140 cm) tall—on the campsite and then calculate a density (such as number of stems/ha). Seedlings are then counted on a control—a 538-ft^2 (50-m^2) circle in the Eagle Cap—and density is calculated again. Subtracting campsite density from control density provides an estimate of the amount of reproduction per unit area (such as, per hectare) that has been lost on the site. Dividing this value by the control density provides an estimate of the proportion of reproduction that has been lost.

One problem with this technique is how to handle reproduction growing in protected places on the campsite. Often all reproduction on the site can be found in protected clumps that are never trampled. In the Eagle Cap study, reproduction in "untrampled islands" was excluded as being unrepresentative of the trampled portion of the campsite. Excluding reproduction in untrampled islands overestimates impact on the campsite and reduces precision because it requires a judgment about whether or not a clump of reproduction should be included. While counting all reproduction within the campsite boundaries may underestimate impact on the trampled portion of the site, this estimate should be more precise and it does provide an accurate representation of impact to the entire site.

Although there appear to be no examples, it should be possible to evaluate the density of reproduction in classes similar to those for density of vegetation in the Parsons and MacLeod (1980) system. These classes could be: same as surroundings, moderately less dense than surroundings, and considerably less dense than surroundings. Because tree reproduction is often more patchily distributed than ground cover vegetation, it can be more difficult to get an accurate and precise estimate.

Shrub Damage—If large resistant shrubs are a significant component of the vegetation, it can be worthwhile assessing damage to shrubs. This might be particularly important in places where trees are lacking and shrubs form the tallest vegetation layer. The only cases I know of where shrub damage has been assessed are in desert environments.

On backcountry campsites at Grand Canyon National Park, Cole (1985) counted number of shrubs and calculated shrub densities on campsites in twenty-five 10.8-ft^2 (1-m^2) permanently located quadrats. Shrub density was determined in a circular 538-ft^2 (50-m^2) control plot. Only shrubs rooted in plots were counted. There was often a problem deciding consistently how many individual shrubs to count in a shrub clump. The decision rule used was to count each clump of stems as one shrub. The main problem with this technique is that shrub density may not reflect impact because trampling damage often results in a higher density of smaller plants. In such cases, cover estimates might be a better choice.

At Canyonlands, classes have been delineated for both damage to shrubs and for root exposure (Kitchell and Connor 1984). On backpacker sites, damage classes are: none show any damage; 10 percent of shrubs show damage (for example, broken limbs, crushed appearance); 10 to 30 percent of shrubs show damage or one or two shrubs show reduced vigor as a result of damage; and >30 percent of shrubs show damage, more than two show reduced vigor, or dead and dying shrubs are present. Root exposure classes are: no roots exposed; roots exposed on one shrub; roots exposed on two shrubs; and roots exposed on more than two shrubs. Including both counts and percentages in a single definition can cause problems. For example, if there are only a few shrubs on the site, one or two damaged shrubs might represent damage to a majority of shrubs.

Damage to Ground Cover Vegetation—Several different aspects of ground cover vegetation damage are regularly monitored. The most common are the area that is devegetated, reduction in vegetation density or cover, and change in species composition. Each of these can and has been measured in permanent sampling units and estimated rapidly.

The Eagle Cap technique (Cole 1982), in addition to measuring the distance from permanent center point to the edge of the campsite, measured the distance from center point to the first significant amount of vegetation, along each of the 16 transects. This was a modification of Schreiner and Moorhead's (1979) use of eight transects without a permanent center point. These end points were plotted on a radial map and the area of the polygon (devegetated area) was determined with a planimeter. As mentioned before, summing the area of triangles is a more rapid means of calculating area.

It is important to decide on a vegetation cover or density that will be considered a "significant amount" of vegetation. The definition used in the Eagle Cap was at least 15 percent cover in a 1.09- by 3.28-ft (0.33- by 1-m) quadrat oriented perpendicular to and bisected by the tape. This boundary can usually be determined more consistently than the edge of the campsite, so estimates of devegetated area should usually be more precise than estimates of camp area. Only where ground cover is very sparse and patchily distributed is it difficult to determine the boundary of the devegetated area.

This technique only measures the area of a devegetated core close to the center of the site. Sometimes there are several devegetated places on a single campsite. These

could all be measured in the same manner, although this would be quite time consuming. The area of these other places could be estimated and added to the central area, without too much loss of accuracy, if they were much smaller than the central area that was measured. It would be unfortunate, however, to significantly contaminate a careful measurement of the central core with rough estimates of other barren places. It is also important to define how large a barren area must be to be included in such an estimate. Perhaps only devegetated areas larger than, say 10 m^2, should be included.

The other alternative is to estimate the area of either the central devegetated area or all devegetated areas. As with camp area, radii, lengths, and widths can be estimated and then the appropriate area formulas can be used to determine area. In most systems only the size of the central area is estimated. This probably results in more precise estimates, although this provides a less useful estimate of vegetation loss on the entire site. Estimates can be either to the closest whole unit of measurement (for example, meter) or sites can be classified. For example, Parsons and MacLeod's (1980) classes for barren core area are: absent, 5-50 ft^2 (0.5-4.6 m^2), 51-200 ft^2 (4.7-18.6 m^2), 201-500 ft^2 (18.7-46 m^2), and >500 ft^2 (46 m^2). Rapid estimate systems for the Bob Marshall (Cole 1983a, 1984) and the Grand Canyon (Cole 1985) also have classes for size of the devegetated center.

Most monitoring systems have used ocular estimates of vegetation cover rather than more precise measurements (for example, by using tools such as a point-frequency frame [Chambers and Brown 1983; Mueller-Dombois and Ellenberg 1974]) of cover or density. Most systems differ primarily in the size of the sampling unit for which cover is estimated.

With the more precise systems, cover is estimated in permanent quadrats—in fifteen to twenty 10.8-ft^2 (1-m^2) quadrats in the system that Cole (1982, 1983b, 1986b) has used in various places, or in ten to twenty 2.7-ft^2 (0.25-m^2) quadrats in the system that Stohlgren and Parsons (1986) have used. Usually cover is estimated to the nearest 5 or 10 percent. The mean cover from all the quadrats provides an estimate of cover on the site. Such estimates should be quite precise; if the sample size is large enough and the samples are properly distributed, the estimate should also be quite accurate.

Few systems have attempted statistical determination of an adequate sample size. Such techniques do exist (see, for example, Chambers and Brown 1983; Mueller-Dombois and Ellenberg 1974). A sample of 5 to 10 percent of the site would probably be adequate in most cases. Because of the pronounced disturbance gradient on campsites from center to periphery, a systematic placement of quadrats provides a more accurate assessment for a given sample size than does a random placement.

The other quantitative alternative is to estimate cover on the entire site. This method is less precise simply because it is difficult to visualize cover of the entire site at one time. This reduction in precision should be reflected in how the data are displayed. For example, it would be misleading, although quite feasible, to record cover to the nearest percent if it could not be accurately estimated even to the nearest 10 percent. For the Bob Marshall system, Cole (1983a, 1984) recommends estimating cover in the following classes: 0-5 percent, 6-25 percent, 26-50 percent, 51-75 percent, and 76-100 percent. This might be improved by dividing the latter category into 76-95 percent and 96-100 percent classes. The midpoints of each category can be used as a single estimate of cover.

With either of these quantitative estimates of cover, the impact parameter of concern is not cover itself, but loss of cover. This can be assessed by estimating cover on an undisturbed control plot and then comparing campsite cover, to cover on a neighboring undisturbed control site. Identical techniques should be employed on both campsite and control. Vegetation loss can be expressed as either the difference between campsite and control as a proportion of the cover on the control. For example, if vegetation cover was 40 percent on the campsite and 80 percent on the control, loss could be either 40 percent (80 percent – 40 percent)—the amount less on the camp—or 50 percent ([80 percent - 40 percent]/80 percent), indicating that half of the vegetation has been lost.

In the Bob Marshall rapid estimate system (Cole 1983a, 1984), vegetation is estimated in categories, both on campsites and on a nearby unused comparative area. The rating for vegetation loss is based on the difference in number of coverage classes between campsite and control. The site is rated 1 (if there is no difference); 2 (if there is a difference of one class); or 3 (if there is a difference of two or more classes). In the Canyonlands system (Kitchell and Connor 1984), cover loss classes, when compared with control, are: <10 percent reduction, 10-30 percent reduction, 31-60 percent reduction, and >60 percent reduction.

Other modifications of this technique could be developed. The important elements are to make estimates in classes that reflect the precision of estimates, to make estimates both on campsites and controls, and then to express vegetation loss in terms of a comparison between the two.

Another alternative is to express vegetation loss in terms that are not quantitatively defined. The Parsons and MacLeod (1980) system asks for a rating of vegetation density as: same as surroundings, moderately less dense than surroundings, or considerably less dense than surroundings. Although not quantitatively defined, these categories probably reflect quantitative differences similar to those just noted.

Vegetation composition has also been assessed in similar terms. Parsons and MacLeod (1980) ask for a rating of composition, relative to surrounding vegetation, of: same as surroundings, moderately dissimilar, or significantly dissimilar.

In Canyonlands (Kitchell and Connor 1984), compositional changes are indicated by the proportion of the cover that consists of exotic and/or disturbance species (Kitchell and Connor 1984). For example, a site with none of these species is given the lowest rating, while a site on which >50 percent of the cover consists of exotic and/or disturbance species is given the highest rating (most impacted).

When estimates of the presence and/or cover of each species are available, both on campsite and control, it is possible to calculate various indexes of the difference in composition between campsites and controls. Cole (1982, 1983b) has calculated an index as follows:

$$\text{Floristic dissimilarity} = 0.5 \times \sum |P_1 - P_2|,$$

where P_1 is the relative cover of a given species on the campsite and P_2 is the relative cover of the same species on the control. Relative cover is the cover of a species expressed as a percentage of the total cover of all species. It is calculated by summing the cover of all species and then dividing the cover of each species by this sum. The sum of the relative coverages of all species on a site will equal 100 percent. Good discussions of indexes that are based on presence or measures of importance other than relative cover, or that utilize other formulas, can be found in Mueller-Dombois and Ellenberg (1974) and Chambers and Brown (1983).

Most of these indexes range from 0 to 100 percent, with higher numbers indicating a greater compositional change. Interpretation is hampered by the fact that there is always some dissimilarity between two samples of the same area of vegetation. This inherent dissimilarity varies between vegetation types and with the sampling procedure and type of index. By comparing several replicate samples of control plots, an idea of inherent variability can be obtained. Unless floristic dissimilarity is substantially greater than this inherent dissimilarity, change in composition should be considered negligible.

An important type of impact in arid environments is disturbance of the fragile cryptogamic soil crusts that are so prevalent in deserts. Cryptogamic soils are formed by algae, fungi, lichens, and mosses growing in a matrix of soil. They often form conspicuous black pedestaled surfaces that are readily destroyed by trampling. In Canyonlands (Kitchell and Connor 1984), cryptogamic disturbance has been assessed with categories ranging from "no disturbance, (crust) still intact in appropriate habitat" to ">60 percent reduction of crust (when compared to adjacent undisturbed area)."

Impacts to Soil Organic Horizons—Three common measures of organic horizon disturbance are reduction in organic horizon cover, reduction in organic horizon depth, and an assessment of the degree to which the litter and duff has been disturbed. Reduction in organic horizon cover is estimated in a manner similar to that of vegetation loss. Estimates of cover can be made either in a set of quadrats or for the entire site. Cover classes are frequently used to reflect the precision level of such estimates. In most cases it is exposure of mineral soil that has been estimated. Mineral soil exposure is inversely related to organic horizon cover because it is only exposed after organic horizons are removed. Campsite cover is compared to cover on a control to determine increase in mineral soil exposure.

A problem that surfaces when estimating mineral soil exposure is how to deal with the situation where most organic matter has been removed but there are still thin patches of litter remaining. An explicit judgment must be made about where to draw the line between bare soil and litter. I have tended to ignore thin, obviously disturbed patches of litter and treat such areas as exposed mineral soil.

There are two common problems with measuring a reduction in thickness of organic horizons. The first is the problem of defining the boundary between organic and mineral horizons. Although this boundary is usually gradational, with training and calibration, consistent definitions can be made. This source of error will be most serious when organic horizons are quite thin (for example, less than 1 to 2 cm).

The more serious problem relates to where to locate samples. The thickness of organic horizons frequently increases from the center of the site to the edge. This pattern is superimposed upon a pattern of random variation in thickness related to litter fall and decomposition rates. Enough samples must be taken to adequately account for the random variation and they must be distributed in a consistent manner, from year to year, relative to the disturbance gradient. If permanent quadrats have been established, a good solution is to take one sample from each quadrat. These locations will be precisely replicated each year and a sample of 15 to 20 measurements should be more than adequate to account for random variations. Without permanent quadrats or a large sample size, it is doubtful that this parameter would change rapidly enough to be measured with sufficient precision.

Again, similar measures must be taken on controls. The difference between measures on campsites and controls provides an estimate of the reduction in thickness of organic horizons.

Parsons and MacLeod (1980) suggest categories based on evidence of disturbance of the organic layers. These categories range from "trampling discernible; some needles broken, scattered cones," to "heavily trampled; (litter) clumped and pulverized; cones absent," and finally to "litter, cones and duff completely absent." Kitchell and Connor (1984) use categories based on the proportion of the litter cover that appears to be crushed or broken. They also note the distribution of litter, whether it is evenly distributed or confined to the edge of the site or protected locations. The highest impact category is assigned to sites in which >60 percent of the litter cover appears crushed or broken and to sites in which >80 percent of the litter occurs around the edge of the site or stable objects.

Impacts to Mineral Soil—In contrast to many of the preceding parameters, most of the methods available for evaluating impacts to mineral soil are time consuming. Consequently, these are seldom estimated except in measurement systems on permanent plots. The most common impacts to assess are soil compaction, water infiltration rates, moisture content, organic matter content, and chemical composition.

Soil compaction has usually been estimated by measuring either bulk density or the resistance of the soil to penetration. Bulk density is the ratio between the dry weight and volume of a soil sample; penetration resistance is a measure of the force required to push a penetrometer a given distance into the soil. Either measure

increases as soil compaction increases. There are a number of alternative methods and tools for each of these measurements (Gifford and others 1977).

Each measure has advantages and disadvantages. Penetration resistance is a simpler measure to take because there is no need to take a soil sample and, if using a pocket penetrometer, the instrument is light. In addition, penetration resistance is a more sensitive measure of impact than bulk density; more subtle increases in compaction can be detected with a penetrometer.

Penetration resistance measures are quite variable in space, and they vary with soil moisture. Therefore, the difference between penetration resistance measures at two points in time may reflect soil moisture rather than a change in level of compaction. This problem can be corrected by taking measures at a standard moisture level, such as field capacity, but this is not practical in most situations; it takes too much time. Another option is to compare the difference between campsite and control at two points in time, assuming that the influence of different moisture levels on campsites and controls would cancel each other out. Unfortunately, it is likely that the magnitude of the effect of moisture levels would differ between campsites and controls.

Another problem with penetration resistance measures is the difficulty of obtaining readings in sandy, rocky, or gravelly soils. Finally, with pocket penetrometers, penetration resistance levels on campsites frequently exceed the maximum resistance that can be measured—4.5 tons/ft^2 (kg/cm^2). Moreover, the instrument is pushed only 0.25 inch (6 mm) into the soil. This may not provide an adequate representation of compaction. For example, it is not uncommon for a highly compacted soil layer to be covered by a centimeter of pulverized soil. The pocket penetrometer would detect no resistance in the upper layer, where most measures are taken. One option here would be to record penetration resistance at various depths in the soil.

Bulk density measures are less variable through space or time; however, they are also difficult to take in rocky or gravelly soil. In such soils, it can be impossible to use a soil corer without distorting the sample; instead, a technique such as the paraffin clod or irregular hole method (Howard and Singer 1981) must be used. These are quite time consuming. Even after using one of these techniques it may be necessary to remove rocks and gravel from the soil samples to obtain a meaningful measure of bulk density. Other researchers have used instruments such as the air permeameter, volumeasure, and gamma ray scattering device (Gifford and others 1977), although these are not practical for use in the backcountry.

As was the case with thickness of organic horizons, there is a gradient of compaction, related to amount of trampling, from the center of the site to its edge. This gradient is superimposed on a pattern of random variation on the site. Therefore, it is important to take an adequate number of samples, to take samples along the entire disturbance gradient, and to make certain that repeat measures reflect a similar distribution of samples.

The requisite number of samples will vary from place to place. It appears that five to 10 samples of bulk density or 10 to 20 measures of penetration resistance are usually needed. It might be useful to separate these samples into core and intermediate locations, as Stohlgren and Parsons (1986) did. They took five to 10 measurements of both bulk density and penetration resistance from core and intermediate parts of the site, as well as from undisturbed controls.

One of the most ecologically significant effects of soil compaction is a reduction in the rate at which water infiltrates soil. As with bulk density, there are standard techniques available to measure infiltration rates. Unfortunately, the most reliable techniques require taking measurements on soils at a standard moisture level, usually field capacity. Otherwise, rates will be strongly influenced by soil moisture levels. This requirement, along with the variability of rates, makes it a time-consuming task to obtain precise and accurate estimates. Sample size and distribution would have to be similar to that just described for bulk density.

Measures of soil moisture, organic matter, and chemistry all require obtaining soil samples that must then be analyzed in a laboratory. Moisture can be determined relatively simply by immediately placing soil samples in airtight containers. Gravimetric moisture is the difference between the weight of the soil sample, before and after being dried, divided by the dry soil weight. Volumetric moisture is the difference in weight divided by the volume of the soil sample. The other methods are more complicated and require more specialized equipment. Again, sample size and distribution should be similar to that suggested for bulk density.

Although these measures of mineral soil characteristics provide relatively accurate estimates of current levels of impact, a prohibitively large number of time-consuming samples must be obtained to identify anything more than the most sizable changes over time. Further work on the development of efficient techniques for monitoring changes in mineral soil impacts would be worthwhile.

At Grand Canyon, soil compaction is being estimated in the following categories: "minimal evidence of surface disturbance"; "much of surface compacted or loosened, but not cementlike"; or "most of surface cementlike in appearance" (Cole 1985). Sites at Canyonlands (Kitchell and Connor 1984) are evaluated in terms of the proportion of the site—from 0 to >60 percent of the site—that has either compacted fine soils or loosened coarse soils. These evaluations are useful in distinguishing between highly compacted and relatively undisturbed sites. The gross categories are not likely to be sensitive enough to detect subtle changes, however. It is also not clear how consistent evaluators can be in categorizing campsites.

Erosion—Only a few systems have attempted to assess erosion in a systematic manner. It is not even clear how common or severe a problem erosion is, since most campsites are located on flat ground. It is particularly difficult to arrive at a quantitative assessment of erosion. Legg and Schneider (1977) used depth to the A2 horizon as a measure of erosion on campsites. They measured depth to this distinctive layer at four points, in each of six quadrats with an Oakfield soil tube. Bratton and others (1978) measured the area on the site with evident erosion. Few other studies have attempted to do more than state

whether or not erosion is evident on the site. This is a parameter that might be assessed with the use of photopoints.

Offsite Impacts—It is also possible to assess the severity of certain impacts that occur off the main part of the campsite. The most common of these are access trails and the impacts associated with firewood collection, confinement of packstock, and the loading and unloading of boats.

Access trails (often called social trails) connect the campsite to the main trail, water sources, and other campsites and attractions. The usual procedure for access trails has been to count them and note whether or not they are well developed and/or eroded. In most cases this information is the basis for categorizing sites. Categories in the Parsons and MacLeod system (1980), for example, range from none, to two trails discernible, to more than two well-developed trails. Problems result when trails are only discernible at certain times of the year and when definitions of the difference between a discernible and a well-developed trail are inconsistent.

Bratton and others (1978) estimated the area disturbed by firewood collection by recording the maximum distance disturbed by firewood collection from the center of the site along at least two axes and then multiplying these measures. They also quantified the reduction in woody fuels, using standard woody fuel inventory techniques on firewood collection areas and undisturbed controls (Bratton and others 1982). While providing information on what impacts have occurred and how large an area is affected, these techniques are not sufficiently precise to identify subtle trends.

Shorelines of lakes and streams are disturbed where visitors travel by boat. Disturbance occurs when boats are loaded and unloaded, as well as during recreational activities along the shore. Marion (1984) has recorded the length of shoreline that has been disturbed at campsites in the Boundary Waters Canoe Area Wilderness. Where the extent of disturbance can be consistantly defined (for example, where vegetation is dense and fragile), this length can simply be recorded to the closest foot, meter, or other unit of length. Where it is more difficult to define the extent of disturbance, categories are more appropriate. Marion's categories ranged from <15 feet of disturbance to >25 feet of disturbance.

Areas disturbed by confined packstock have been included in estimates of the total area of disturbance around campsites and in counts of tree damage in the Bob Marshall Wilderness (Cole 1983b). Schreiner and Moorhead (1979) specifically counted the number of "horse trample areas within 100 feet" of the campsite. The value of and problems with these techniques have already been discussed in the sections on campsite area and damage to overstory trees.

Summary Ratings—Summary ratings and condition class ratings provide a means of summarizing all of these impact parameters in a single rating. They can be constructed, as Frissell (1978) did, by noting the presence or absence of certain conditions. For example, if vegetation is lost on some of the site, but not most of the site, the site is given a rating of 2. If tree roots are exposed, but trees are not dead or reduced in vigor, the site is given a rating of 4. This is an appropriate procedure and, if the most important impact parameters are included, will provide an accurate and precise summary rating of impact levels. Review the discussion of Frissell's condition class in step 1 for problems with the technique and recommendations for how these problems can be alleviated. A condition class summary rating could be assessed, in addition to estimates or measurements of individual parameters, as an indicator of overall condition.

The summary ratings calculated by summing ordinal ratings, with or without determining a mean (Cole 1983a, 1984, 1985; Kitchell and Connor 1984; Marion 1984; Parsons and MacLeod 1980), use mathematically improper procedures. Categorical ratings cannot be combined into a readily interpretable single summary rating (Schuster and Zuuring 1986). Although conclusions about the relative impact level of sites with widely divergent ratings are probably valid, conclusions about sites with ratings close to each other are suspect. Perhaps the practice of grouping these ratings into four or five categories overcomes this problem. Because these systems have not been adequately tested, however, we do not know.

Instead of calculating a mean from categorical ratings, classes of sites could be defined in terms of the presence or absence of certain conditions. For example, a class 5 site could be any site that received a rating of 5 for more than two parameters. A class 1 site could be one that was rated 1 on at least six parameters, regardless of what the other ratings were. Or a class 1 site could be one that received no ratings higher than 2. Obviously there are countless ways to define overall ratings. Refer to the section on calibration in step 3 for description of techniques that will facilitate definitions that provide an adequate differentiation of site variability.

Research Needs

Evaluation procedures are clearly deficient in several respects and could be improved by further research. More work is needed to increase precision of measurement, particularly for the rapid estimation procedures. We must learn to report results in units that reflect the precision of the techniques used. Reporting the area of a campsite to the closest square meter, when it can only be reliably reported to the closest 10 m^2, is inappropriate and misleading. Thus more work must be done on establishing precision levels (see step 3).

Of the types of impact that have been assessed, techniques for measuring impact to the mineral soil are the least sensitive, most time consuming, and most difficult to interpret. Further development of these techniques, with suggestions particularly for rapid estimation techniques, would be useful.

Finally, more work is needed to develop appropriate summary impact ratings that provide a meaningful index of how much impact has occurred. Several options have been suggested, but with further thought better techniques might emerge. In addition, all of these alternatives need to be evaluated.

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STEP 3. TESTING OF MONITORING TECHNIQUES

At this stage, impact parameters and procedures for evaluating these parameters have been developed. Although it is tempting at this point to rush off into a season of monitoring, it is more efficient to invest some time and energy in testing procedures. This will expose problems that are likely to arise before they jeopardize consistent and accurate results. It will also identify subtle modifications that will improve the system. Three different types of testing can be appropriate here. With the exception of those systems based entirely on photographs, all systems will profit from refinement of field techniques and from estimation of measurement error. If using a system with categorical ratings, it is also important to calibrate the system (see below for definition of calibration).

Refinement of Techniques

This step is difficult to describe because it can be dealt with in so many different ways. Basically, it involves trying out proposed techniques on a few sites to see how well they work and then coming up with ways to deal with any problems that do arise. A variety of sites differing in environmental conditions and levels of impact should be examined by different people. One common product of this process is a set of quantitative definitions for conditions to be judged in the field. For example, when measuring distance from the center of the plot to the first significant amount of vegetation, it is necessary to define what a "significant amount of vegetation" is. Other definitions might include what is or is not a tree mutilation or when a mutilation becomes "highly obtrusive." These definitions should be developed during the refinement stage. After trying them, some procedures may be determined to be too time consuming or not sufficiently useful or precise. They can be dropped or alternative procedures can be developed. As many of these decisions as possible should be made before sending out the field crews.

The end product of this step should be careful descriptions of all techniques to be used when evaluating each impact parameter, as well as precise definitions of any terms that might be ambiguous. All of the decisions regarding techniques and definitions need to be carefully documented (see step 4).

Calibration Procedures

Many monitoring systems utilize categorical ratings for each impact parameter. These can be quantitatively defined classes, such as for campsite area: 1 = <500 ft^2 (<46 m^2); 2 = 500-1,000 ft^2 (47-186 m^2); and 3 = >1,000 ft^2 (>186 m^2). They can also be nonquantitative. For example, development classes could be: 1 = no development; 2 = a simple rock firering; and 3 = more than one firering or other developments.

To be most efficient at differentiating between sites on the basis of amount of impact, approximately equal percentages of sites should fall into each category. Marion (1986) describes a method for calibrating categories that are quantitatively defined. First, inventory a sample of sites (perhaps 50) that represent the full range of use-, environmental-, and impact-related conditions present in the area for which the system is being designed. This can also aid in the refinement of techniques (as described above).

Second, display these results as a cumulative frequency distribution and then divide this distribution into classes with an equal number of sites. For example, if three categories were to be defined and 33 percent of the campsites were <600 ft^2 in area, the first category should be 0-600 ft^2. The upper bound of the second category would be the area of the site at the 67th percentile. Although these are the most equitable boundaries, it is worth rounding categories so that they are easier to remember and work with. For example, if the area of the campsite at the 67th percentile was 1,061 ft^2, it would be a good idea to set the boundaries at either 1,000 or 1,100 ft^2.

If categories are not quantitatively defined, calibration is more difficult and, in some situations, may not be possible. If the majority of sites have no development, for example, there is no way to have an equal distribution among categories for the development parameter. With such parameters, try several different sets of categories and select the set that provides the most equitable distribution of sites among categories.

Estimation of Measurement Error

Error is inherent to all measurement systems. For monitoring purposes, we need to be able to distinguish, when comparing measures of the same campsite at two different times, between two different measures of the same condition (measures that differ due to the biases and interpretations of two different evaluators) and a real change in conditions. To do this we need to (1) develop techniques with as little inherent measurement error as possible, (2) do everything possible—through training and documentation—to minimize measurement error, and (3) determine the magnitude of measurement error. While we have made considerable progress on the first two needs, estimates of the measurement error inherent to any monitoring system have never been provided. This may be the most critical missing link in our ability to accurately monitor changes in campsite condition. At this stage, we have little ability to evaluate the probability that an observed change is either a real change or simply a result of measurement error.

The details of how to evaluate measurement error have yet to be developed. In a report prepared in conjunction with this project, Steele (1987) suggests some methods for evaluating and displaying measurement error. Because monitoring data consists of only one observation per time period, there is no opportunity to evaluate, statistically, variation and error for actual monitoring data. Therefore,

it will be necessary to conduct separate studies designed specifically to estimate error. If a number of different people independently evaluate conditions on the same site, these evaluations can be statistically manipulated to estimate the error associated with different parameters. The appropriate number of different people and different number of sites has not been determined. At a minimum, there should probably be five to 10 people evaluating 10 to 20 representative campsites.

In order to decide on appropriate statistical techniques, the distribution of each variable must be determined. Many tests are only appropriate if the distribution of a variable either approximates a normal distribution or can be transformed so that it approximates a normal distribution. Many of the count and class variables clearly are not normally distributed. Some may follow a Poisson distribution; for others it is not clear exactly what statistical tests to apply.

For those variables that are normally distributed, the relative sensitivity of different parameters can be evaluated by examining their coefficient of variation (the ratio of the sample standard deviation to the sample mean, expressed as a percentage). A large coefficient indicates that the variability of independent estimates is high, the sensitivity of the variable is low, and measurement error is high. For variables with a large coefficient of variation, the difference between two observations must be relatively large before it is safe to conclude that a real change has occurred. For such variables, significant deterioration is likely to occur before one can be confident that a real change has occurred.

Quantitative estimates of measurement error for specific parameters can be approached in several ways. One option is to determine the minimum change that, if observed, will permit one to conclude, confidently, that a change has actually occurred. This requires the specification of a confidence level, the risk one is willing to assume of stating that a change has occurred when it has not. By setting this level (type I error), minimum change can be determined through use of the two-sample *t* statistic (Steele 1987).

It is also worth evaluating the likelihood of **not** detecting a change that has actually occurred. This risk is called type II error. Power curves can be constructed (Steele 1987) that permit type II error to be determined for any combination of confidence level (type I error) and magnitude of real change. For example, given that a real change of 10 percent actually occurs, and one is willing to accept a 1-in-10 chance of incorrectly concluding that a change has occurred when it has not, the likelihood of correctly detecting that 10 percent change is the power ([1 – type II error] * 100 percent), as read from power curves.

The utility of the coefficient of variation, the two-sample *t* statistic, and power curves can be illustrated with examples from a small sample of campsites taken near Missoula, MT. Five separate sites were independently evaluated by nine graduate students from a University of Montana recreation management class. The parameters used were generally those of Cole's rapid estimation procedure used in the Bob Marshall (see appendix H); a few additional parameters were also added. Values may be somewhat unrepresentative because the observers received less training than normal, not all variables met the assumptions of a normal distribution, and the number of sites examined was probably insufficient. Nevertheless, these examples illustrate some of the ways in which measurement error could be examined; they also suggest which variables are most sensitive and the magnitude of measurement problems.

Coefficients of variation (table 2) indicate that all of the rating variables, except for trash, are more sensitive than those that require a numerical estimate. Two of the three least sensitive variables were ones not used in the Bob Marshall—the trash rating used at Canyonlands (Kitchell and Connor 1984; appendix I) and the measure of bare mineral soil area used at the Delaware Water Gap (appendix J). Impact index proved to be quite sensitive; the standard deviation was typically only 7 percent of the mean index. It should be possible to confidently conclude, then, even for relatively small increases in this index, that an increase represents a true increase—rather than simply random variation between observers. In contrast, observed increases in the number of trees with exposed roots and the area of bare mineral soil must be large before it is possible to conclude, with much confidence, that the increase is a true increase.

A better idea of how large changes must be before one can conclude, with confidence, that a change has occurred can be derived from table 3. This table shows the minimum magnitude of change that can be detected, given type I error rates of 0.05 and 0.25; these correspond to 1-in-20 and 1-in-4 chances of incorrectly stating that a change has occurred when there has been no change. Expressing this "minimum detectable change" as a percentage of mean observations (the values in parentheses in table 3) provides another measure of relative sensitivity; the order of parameters in table 3 is roughly comparable to that in table 2. A value of 50 percent suggests that a future observation must be at least 50 percent

Table 2—Coefficient of variation for monitoring parameters, using data collected on five sites by nine recreation management graduate students

Parameter	Coefficient of variation Median	Range
Camp area (rating)	0	0 - 21
Vegetation loss (rating)	0	0 - 36
Root exposure (rating)	0	0 - 55
Impact index	7	4 - 8
Development (rating)	12	0 - 20
Barren area (rating)	12	0 - 41
Tree damage (rating)	19	0 - 21
Mineral soil increase (rating)	20	12 - 38
Cleanliness (rating)	22	0 - 36
Social trails (rating)	27	0 - 38
Camp area (ft²)	31	26 - 34
Social trails (number)	31	16 - 47
Fire scars (number)	31	0 - 110
Barren area (ft²)	31	27 - 106
Tree damage (number)	37	24 - 62
Trash (rating)	38	19 - 42
Root exposure (number)	44	24 - 163
Bare mineral soil area (ft²)	53	31 - 102

Table 3—The minimum amount of change that, if observed, can confidently be considered a "real" change, based on data collected on five sites by nine recreation management graduate students

Parameter	Minimum change[1]			
	0.05[2]		0.25[2]	
Camp area (rating)	0.3	(13)	0.1	(4)
Impact index	3.3	(15)	1.3	(6)
Development (rating)	0.5	(21)	0.2	(8)
Root exposure (rating)	0.5	(23)	0.2	(9)
Vegetation loss (rating)	0.7	(26)	0.3	(11)
Tree damage (rating)	0.9	(34)	0.4	(15)
Barren area (rating)	0.9	(36)	0.4	(16)
Cleanliness (rating)	0.8	(44)	0.3	(17)
Social trails (rating)	1.2	(47)	0.5	(19)
Mineral soil increase (rating)	0.1	(52)	0.4	(20)
Social trails (number)	3.5	(72)	1.4	(29)
Camp area (ft^2)	1,556	(72)	628	(29)
Fire scars (number)	1.6	(78)	0.6	(30)
Root exposure (number)	4	(79)	2	(30)
Trash (rating)	1.8	(80)	0.7	(31)
Barren area (ft^2)	520	(87)	210	(35)
Tree damage (number)	12	(92)	5	(38)
Bare mineral soil area (ft^2)	295	(104)	119	(42)

[1]Minimum change is the minimum difference between observations, taken at two different times, that would allow the null hypothesis, of no difference, to be rejected. The two-sample *t* statistic, with a pooled estimate of the standard deviation and 40 degrees of freedom, was used. Values in parentheses express this minimum change as a percentage of mean values and provide a measure of sensitivity.

[2]Type I error rates of 0.05 and 0.25 are reported, providing confidence levels of 95 percent and 75 percent, respectively.

Table 4—The likelihood of correctly detecting a real change of an increase in rating of 1 for the rating parameters, based on data collected on five sites by nine recreation management graduate students

Parameter	Chance of detection[1]	
	0.05[2]	0.25[2]
Camp area	100	100
Development	90	100
Root exposure	90	100
Vegetation loss	75	95
Cleanliness	65	90
Tree damage	60	85
Barren area	55	85
Mineral soil increase	50	80
Social trails	40	75
Trash	20	60

[1]Chance of detection is 1 minus the type II error rate, expressed as a percentage, as derived from power curves in which both type I error rate and a given magnitude of change are set. For example, a 90 percent chance implies (given that a shift in rating of one has actually occurred) that there is a 90 percent chance of correctly rejecting the null hypothesis, that no change has occurred.

[2]Type I error rates of 0.05 and 0.25 are reported, providing confidence levels of 95 percent and 75 percent, respectively. Using tree damage as an example, if you are willing to accept a one-in-four chance of saying there has been a change when none has occurred (type I error of 0.25), you have a greater than four-in-five chance of correctly identifying a shift of one; if you are only willing to accept a 1-in-20 chance of saying that there has been a change when none has occurred, the odds of correctly identifying a shift of one drop to a greater than 6-in-10 chance.

larger than the estimate of current condition before it is safe to conclude that a change has occurred. Again it is clear that all of the parameter ratings, except for trash, are quite precise. If an increase in rating of 1 is observed, there is very little chance of concluding incorrectly that an increase has occurred when it has not. Only for social trails and mineral soil increase is there a 1-in-20 chance of making this mistake. Impact index is also relatively precise; it is highly unlikely that an observed change of more than two or three units (on the scale of 9 to 27) does not reflect a real change. In contrast, one out of every four times that a change in bare mineral soil area as large as 119 ft^2 (11 m^2) is reported, there is likely to have been no real increase.

The minimum detectable change in vegetation cover (for a type I error of 0.05) was 25 percent on campsites and 17 percent on controls. The corresponding minimum changes in mineral soil were 26 percent and 5 percent on campsites and controls. This suggests that the 25 percent cover classes used in the Bob Marshall (appendix H) are about right, although it might be desirable to divide the 76-100 percent class into 76-95 percent and 96-100 percent classes to accommodate the greater sensitivity of mineral soil estimates on controls.

Although knowledge about the minimum detectable change is critical, it is also enlightening to examine the likelihood of **not** detecting a real change in conditions. Tables 4 and 5 show the likelihood of correctly identifying a real increase in rating of 1 (for the rating parameters) and a real 25 percent increase in deterioration (for the other parameters), respectively. A rating shift of 1 should usually be detected without having to accept too much risk of making a type I error. In contrast, for none of the parameters that require a count or estimate is there more than a 50 percent chance of detecting a 25 percent increase in deterioration, even accepting a 1-in-4 risk of saying there has been a change when none has occurred.

In conclusion, we have only begun to investigate the difficult and complex issue of measurement error. The results reported here should be treated as merely

Table 5—The likelihood of correctly detecting a real 25 percent increase in deterioration, based on data collected on five sites by nine recreation management graduate students

Parameter	Chance of detection[1]	
	0.05[2]	0.25[2]
Impact index	85	100
Camp area (ft^2)	20	50
Tree damage (number)	20	50
Fire scars (number)	20	50
Barren area (ft^2)	15	45
Social trails (number)	15	45
Root exposure (number)	15	45
Bare mineral soil area (ft^2)	15	45

[1]Chance of detection is 1 minus the type II error rate, expressed as a percentage, as derived from power curves in which both type I error rate and a given magnitude of change are set.

[2]Type I error rates of 0.05 and 0.25 are reported, providing confidence levels of 95 percent and 75 percent, respectively.

suggestive of the precision levels of the various estimation techniques used. They demonstrate that most of the interval scale measures are highly imprecise; they are much less sensitive than they appear. For a variable such as camp area (which is typical of these parameters), area must virtually double before it is safe to conclude that a real change has occurred. Consequently, there is a high probability of either stating a change has occurred when it has not or failing to detect even sizable changes. Ratings, while they provide less information, are less misleading. When a shift in rating occurs, it is likely to be detected; conversely, when a shift in rating is observed, it is likely to reflect a real change. Finally, the impact index (used to summarize overall impact) appears to also be sensitive and relatively precise. One can be quite confident of detecting changes as small as 10 to 15 percent and confident that changes of 10 to 15 percent reflect actual changes.

Research Needs

More research is needed on measurement error. More studies with larger sample sizes need to be conducted following the format of the study reported here. From these it should be possible to determine appropriate sample sizes for such studies, as well as the approximate distributions for different parameters. For those parameters with distributions that are not normally distributed, particularly class variables, it will be necessary to find tests comparable to those available for parameters that are normally distributed.

Once appropriate distributions are determined, it should be possible to more accurately determine the magnitude of measurement error for different parameters. Through research it should be possible to identify those parameters that are most sensitive. It might also be possible to suggest ways to increase the sensitivity of parameters with large errors. Ultimately, managers of individual areas will have to utilize baseline studies and statistical procedures to determine appropriate error terms for the procedures they adopt. These errors can be used to decide how large a change must be before it will be considered a real change.

Sources of Information

Marion, Jeffrey L. 1986. Campsite assessment systems: application, evaluation, and development. In: Popadic, Joseph S.; [and others], eds. Proceedings, 1984 river recreation symposium; 1984 October 31-November 3; Baton Rouge, LA. Baton Rouge, LA: Louisiana State University, School of Landscape Architecture: 561-573. (Describes a procedure for calibrating categorical impact rating systems.)

Steele, Brian. 1987. Statistical procedures for the analysis of a campsite monitoring program. Unpublished report on file at: Systems for Environmental Management, Missoula, MT. 56 p. (Suggests statistical procedures for evaluating measurement error. Provides examples from a sample of five campsites that were evaluated independently by nine people.)

STEP 4. DOCUMENTATION AND TRAINING

Although it is possible at this stage to plunge into the inventory and monitoring fieldwork, it is important to invest time in training and documentation of methods. If this is not done, consistency and precision will be low; this will reduce the value of the data collected.

The purpose of this step is to minimize the errors associated with different people taking measurements and making judgments. Two sources of error are common to these techniques. The first results from problems of definition. For example, when measuring campsite area or counting tree damage, estimates will be highly divergent if evaluators have very different opinions about how to define the campsite boundary or what constitutes a "damaged tree." Problems of definition can be just as serious when using precise measurements in permanent plots as they are when making rapid estimates. Precise definitions must be worked out in the field, documented in some manner, and then communicated to evaluators through training. Separate evaluators should be periodically brought together to be recalibrated—to make certain that definitions and judgments remain consistent.

The second source of error is in measurement technique. This error is likely to be more substantial when using rapid estimation techniques. In measuring campsite area, for example, it is difficult to measure the area of an irregular figure. If one evaluator estimates area on the basis of radial measures of the distance between center point and boundary, while another pieces together the areas of several simple geometric figures, results are likely to be very different. Even when counting damaged trees, estimates will vary depending on whether or not only onsite trees are counted. Measurement/estimation techniques need to be agreed on and used in a consistent manner. The magnitude of the measurement error will vary with the measurement technique used. This provides another reason for using consistent techniques.

Documentation

Once precise evaluation procedures and definitions have been established, the consistency of their application must be maintained. This can be particularly difficult when field crews and even supervisors change from year to year. An important tool for dealing with the problem of turnover is the preparation of an impact monitoring system manual that documents techniques and definitions. This tool will also increase year-to-year consistency in places that do not experience turnover. Without such a manual it is doubtful that anyone monitoring sites, say, 20 years from now, will be able to use the data being collected today.

Several types of information should be included in such a manual. Much of the manual will consist of step-by-step descriptions of how each impact parameter should be evaluated. These should be described in as much detail as possible, in simple language. If measurement instruments are needed, these should be listed, described, and perhaps even photographed. The more detail, the better.

Definitions of ambiguous terms, such as what constitutes a "damaged" tree or "highly obtrusive" damage, are a critical part of the manual. Definitions should be quantitative where possible. Particularly where quantification is not possible, photographs of the conditions being described will contribute to consistent judgments in the field. For example, photographs of a variety of trees with "highly obtrusive" damage, damage that is not "highly obtrusive," and no damage at all would help greatly where these terms must be used. Other examples might include the difference between "some" and "much" litter, or the difference between a "discernible" and a "well-worn" access or social trail.

Often it is important to document things that will or will not be included in an estimate. In some places, measures of "barren area" have been confined to the devegetated area around the central core of the site; in other places, several devegetated areas on the site have been measured and summed. When counting access trails for campsites located at a lake, for example, decisions must be made about whether or not to count a fisherman's trail around the lake that happens to run through the site. Logically such trails might be excluded if they would have been there regardless of the campsite's existence. It is always helpful to explain the rationale behind such decisions.

Helpful "pointers" and "rules of thumb" are also useful. Examples include how to decide whether or not a site should be considered a campsite and how to "split up" an area of intermingled sites into separate sites for inventory purposes. Shortcuts and recommendations for how to speed up estimates are also useful.

The manual should be updated when new suggestions and improvements are developed. Field workers should carefully document situations that are not clearly addressed in the manual and suggest means of dealing with these new situations. These can then be discussed with a supervisor who can evaluate the situation and suggest changes, as well as the need for revision of the manual. Keeping a copy of the manual on a word processor should make the process of manual revision simpler.

Whenever changes in procedure or definition are made, it is important to evaluate how such changes will affect comparability with data already collected. If comparability will be lost, a decision on whether or not to make a change must be dependent on a weighing of the advantages of the improved method and the disadvantages of lost information. While one should not be afraid to lose the information contained in previous measurements, this loss should not be accepted unless improvements are substantial. If comparability is lost, this should be stated in the manual, along with any suggestions for how previous measurements might be interpreted in relation to new methods.

Training

There are many useful ways to conduct training, but several guidelines can be suggested. Evaluators can study the documentation manual independently, but they should be trained as a group. Definitions and procedures should be discussed and demonstrated in the field. Examples of the various situations that require different judgments should be viewed and discussed as a group. Then evaluators should each work independently on a series of sites. Results should be compared and discussed. This process must be repeated until an acceptable level of consistency is reached. If one or several evaluators consistently overestimate or underestimate a parameter, they should be instructed to compensate their judgments in such a way that they are calibrated with the group as a whole. Repetition must continue until this compensation leads to consistent results—within an acceptable measurement error.

Periodic reevaluation of the consistency of judgments throughout the field season will also increase precision. If evaluators can be reconvened for a few hours every month or so, internal consistency can be examined and any problems or suggestions for improvement can be discussed.

Where possible, the same supervisors should do the training each year. Where this is not possible, the new supervisor should be trained, in detail, by the previous one. This is critical if consistent calibration of field workers from year to year is to be maintained. The manual will help in this regard, as would the sharing of training responsibilities—so it is less likely that all supervisors will leave in any one year.

STEP 5. FIELD DATA COLLECTION PROCEDURES

To increase efficiency in the field and accuracy in the reporting of data, it is important to develop efficient data collection procedures.

Data Forms

Carefully constructed data forms can make data collection much simpler. Spaces for recording information should be arranged in the order in which data will be collected. Otherwise evaluators may have to flip back and forth between pages. Sometimes it is helpful to have one page on which data is recorded and a separate page with details on methods, judgments that must be made, and category descriptions. Forms and shorthand codes should always be standardized so that problems in interpreting data are minimized. If precipitation occurs frequently during the data collection season, it may be necessary to print forms on waterproof paper and use pens that can write on wet paper.

The Code-A-Site system (Hendee and others 1976) used edge-punched cards in the field. This permitted the use of needle-sorting methods for sorting and retrieving data; computers were not needed. Needle-sorting proved to be cumbersome and the raw data, once retrieved, often had to be tabulated and summarized manually. Recent increases in the accessibility of electronic data processing capabilities have rendered this approach virtually obsolete.

The process of taking data off a form and entering it into a computer is time consuming and subject to error. Problems resulting from this translation can be reduced by using standard precoded forms with data recorded spatially on the form in such a way that they correspond to the

columns and data fields established in computer files. It is important, however, for the form to be easily interpretable in the field. If actions taken to reduce errors in data entry result in more errors in data collection, nothing is gained. Where possible, data manipulation and transformation prior to data entry should be avoided. Most of this manipulation can be accomplished through computer programming.

Electronic Field Data Recorders

Recent technology makes it feasible to carry programmable, battery-operated, hand-held microcomputers into the field. Data can be entered directly, eliminating the need for forms entirely. Prompts, such as "how many damaged trees are there?" and "are any of them highly obtrusive?" can be programmed into these devices. Illogical answers can be flagged as probable errors. Although these devices possess data processing capabilities, their primary function is field data entry and temporary storage. After leaving the field, collected data are downloaded into nonportable computers.

Currently (1988), such devices cost between $500 and $1,000. Depending on one's budget and the number of workers that need one, this cost may or may not be prohibitive. Cost is likely to decline some in the future. Important criteria for a system include durability, weight and compactness, battery life between charges, screen size and legibility, data storage capacity, and the type of operating system. This latter criterion is important because certain operating systems provide greater flexibility in interfacing with nonportable computers and are more user friendly.

Research Needs

Further work in the development of portable data recorders and software to facilitate data collection would be worthwhile.

Sources of Information

Krumpe, Edwin E. [Personal communication.] Department of Wildland Recreation Management, University of Idaho, Moscow ID. (Has developed a portable data recorder for field collection of monitoring data.)

Sydoriak, Charisse A. [In press]. Yosemite's wilderness trail and campsite impacts monitoring system. Paper presented at the National Park Service Science Conference; 1986 July 13-18; Fort Collins, CO. (Mentions the portable data recorders used in the field in Yosemite. More information is available in appendix K or by directly contacting the Resources Management Division at Yosemite National Park.)

STEP 6. DATA ANALYSIS AND DISPLAY

Once monitoring data has been collected, it must be analyzed and displayed. The detail and sophistication used at this step can be highly variable. Data forms can be examined in a cursory manner; they can be needle-sorted (if Code-A-Site forms are used); or data can be entered into a computer. In most cases data should be summarized in statistics, graphs, and maps. Although the level of analysis is likely to vary with management objectives and analytical capabilities, both current campsite conditions and trends in condition should be examined. Some suggested analysis procedures, organized under these two headings, follow. Any of these analyses that appear unnecessary can simply be ignored. A discussion of the use of computers and software to facilitate analysis is included in a concluding section.

Analysis of the Current Situation

A variety of analyses can be conducted to evaluate the current condition of campsites. Several of the more important types are as follows:

1. It is useful to be able to retrieve data for any individual site of interest, or for all sites in a destination area or management area. For example, table 6 lists the size of all campsites on Minisink Island on the Delaware River. The ability to retrieve data for individual sites easily facilitates planning for management of both individual sites and larger areas, such as Minisink Island. Where there are a large number of sites, however, analysis at this level of detail is cumbersome.

2. A simple type of analysis, at a more general level, is to calculate summary descriptive statistics for all campsites in the entire wilderness, in individual management units, or in destination areas within the wilderness.

Table 6—Camp area (m^2) for each of the 10 campsites on Minisink Island at Delaware Water Gap National Recreation Area

Campsite number	Campsite location	Camp area
		m^2
20	Minisink	79
23	Minisink	84
24	Minisink	221
26	Minisink	18
28	Minisink	507
29	Minisink	241
30	Minisink	72
31	Minisink	392
32	Minisink	72
33	Minisink	108

Separate summary statistics can be calculated for each individual impact parameter and a summary rating, if one was used. An example would be the median and range for the number of damaged trees on campsites in the entire area or around a certain lake of concern. Medians are often more appropriate measures of central tendency than means because they are not skewed by extreme values.

Summary statistics can be used to assess impact levels, both in the entire area and in portions of the area. As an example, refer to some output from data collected on campsites in the Delaware Water Gap National Recreation Area. Summary statistics for two river segments are compared in table 7. Both an idea of impact levels and differences in impact between segments are revealed. The only pronounced difference between segments is that campsites along the stretch from Bushkill to Smithfield tend to be larger. Campsites on this segment have lost more vegetation, but the extent of shoreline damage is less.

The number of campsites in the wilderness provides an important indication of impact. The number and percentage of all sites for each management area or destination area can be displayed. See, for example, table 8. The river segment with the most campsites is Bushkill to Smithfield. Illegal sites, however, are much more common on the Milford to Dingmans and Dingmans to Bushkill segments. This suggests that more legally designated sites might be needed between Milford and Bushkill.

Further insights into impact levels can be gained by dividing the range of impact into categories and displaying the number and percentage of sites in various categories. In the example in table 9, almost half of the campsites between Milford and Dingmans are in the smallest size class— <1,076 ft^2 (<100 m^2). Successively smaller proportions are found in the larger size classes. Campsites between Bushkill and Smithfield were also skewed toward the smaller size classes, but not as dramatically. Only 40 percent of sites were in the smallest class and more than 10 percent were in the largest class.

Table 10 shows the number of campsites in each of five condition classes for different destination areas in Sequoia and Kings Canyon National Parks. Differences in numbers of campsites are readily apparent. Converting the data into percentages and displaying them in histograms makes differences in the relative frequency of condition classes more apparent (fig. 1). The Dusy Basin area has a very large number of campsites, but few of the sites are severely impacted. At Bubbs Creek, there are fewer sites but a large proportion of the sites are severely impacted. This type of analysis is most useful for comparing levels of impact in different areas.

At Sequoia and Kings Canyon National Parks, overall impact ratings have been calculated for entire destination areas (Parsons and Stohlgren 1987). Although individual sites are given ratings between 1 and 5, it is clear that impacts on class 5 sites are more than five fold those on class 1 sites. The ratings 1 through 5 were replaced by weights based on campsite area. For example, a site with

Table 7—Campsite conditions on the Milford to Dingmans (M-D) and Bushkill to Smithfield (B-S) river segments at Delaware Water Gap Recreation Area

	River segment			
	M-D		B-S	
	Median	Range	Median	Range
Camp area (m^2)	202	18 - 775	286	10 - 3,071
Bare mineral soil (m^2)	88	0 - 483	95	0 - 1,042
Damaged trees (number)	3	0 - 17	4	0 - 16
Tree stumps (number)	1	0 - 5	2	0 - 35
Shoreline disturbance (m)	12	0 - 57	7	0 - 36
Trees with exposed roots (number)	1	0 - 6	1	0 - 8
Firerings (number)	1	0 - 6	1	0 - 4
Vegetation loss (percent)	35	–25 - 75	40	–25 - 75

Table 8—The number of legal and illegal campsites on different river segments at Delaware Water Gap National Recreation Area

	Legal sites		Illegal sites		Total sites	
River segment	Number	Percent	Number	Percent	Number	Percent
Above Milford	5	2.8	9	5.0	14	7.8
Milford to Dingmans	20	11.2	16	8.9	36	20.1
Dingmans to Bushkill	29	16.2	20	11.2	49	27.4
Bushkill to Smithfield	58	32.4	7	3.9	65	36.3
Below Smithfield	4	2.2	11	6.1	15	8.4
Totals	116	64.8	63	35.2	179	100.0

Table 9—Frequency distribution, by campsite area category, for campsites on the Milford to Dingmans (M-D) and Bushkill to Smithfield (B-S) river segments at Delaware Water Gap National Recreation Area

Campsite area (m^2)	River segment: M-D Number	M-D Percent	B-S Number	B-S Percent
0 - 100	17	47	26	40
101 - 300	10	28	22	34
301 - 600	5	14	7	11
601 - 900	4	11	3	5
>900	0	0	7	11
Total	36	100	65	100

Table 10—Number of campsites, by condition class, in destination areas in Sequoia and Kings Canyon National Parks (Parsons and Stohlgren 1987)

Destination area	Condition class 1	2	3	4	5	Total sites
	- - - - - - Number of sites - - - - -					
Goddard Canyon	37	33	33	19	15	137
McClure Meadow	85	87	51	23	19	265
Ionian Basin	35	22	13	0	4	74
Cartridge Creek	59	35	4	0	0	98
Rae Lakes	116	108	63	31	5	323
Hamilton Lakes	3	3	3	14	2	25
Hockett Meadows	102	87	58	20	23	290
Dusy Basin	168	94	28	2	0	292
Bubbs Creek	30	24	31	20	13	118

an area rating of 5 is, on average, 150 times larger than a site with an area rating of 1. Assuming, then, that total area is the most appropriate indicator of total impact, and that the total area rating will probably be the same as the entire campsite class rating, weights for class 1 through 5 sites are 1, 6, 30, 75, and 150. To determine the total impact of each destination area, the number of campsites in each class is multiplied by these weights; then these products are summed to get the total weighted value. Figure 2 shows the campsites at Lake Reflection, their campsite classes, and the calculation of the total weighted value for the lake.

The total weighted value and the weighted value/site allow comparisons between different destination areas. The total value provides a perspective on aggregate impacts in an area. Destination areas vary greatly in size, however, so areas with a larger total may not necessarily have more impact per unit area. The total value/site provides a perspective on how impacted the average site is.

The problem with this procedure is in the selection of weights. Although basing weights on total camp area is probably as defensible as any other single criterion, assigning interval values, after the fact, to ordinal rankings is inevitably suspect. Is an area with one class 5 site really

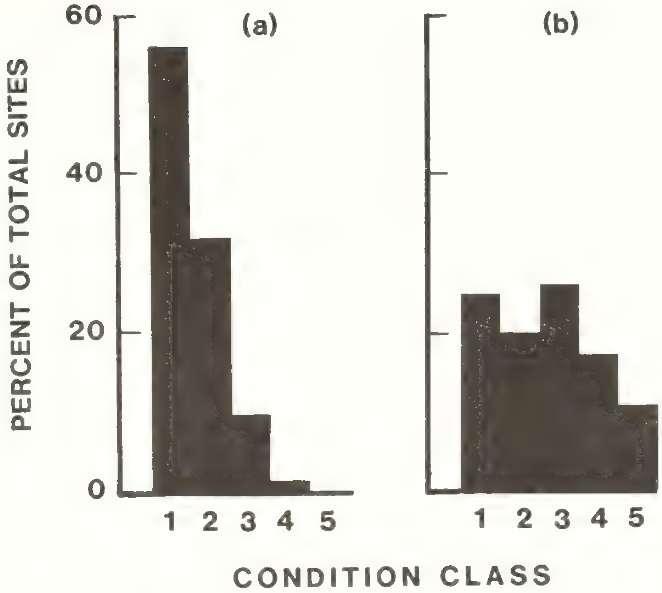
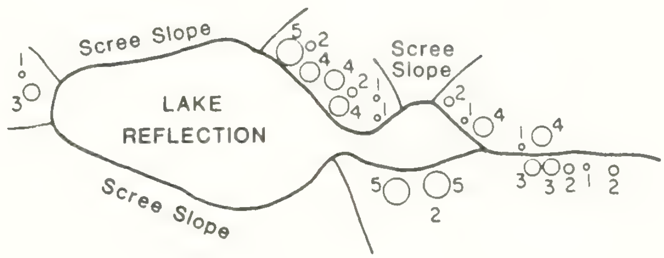


Figure 1—Percentage of total sites in each condition class, for the (a) Dusy Basin and (b) Bubbs Creek destination areas in Kings Canyon National Park.



Campsite Class	No. Sites		Weighting Factor		Weighted Value
1	6	x	1	=	6
2	6	x	6	=	36
3	3	x	30	=	90
4	5	x	75	=	375
5	3	x	150	=	450
	Total Weighted Value			=	957

Figure 2—Distribution of campsites and condition classes at Lake Reflection in Kings Canyon National Park. Calculation of a weighted value for the destination area is illustrated.

Table 11—Rank ordering and percentiles, according to size, for campsites on Minisink Island

Site number	Size	Percentile
	m^2	
120	507	85
116	392	76
119	241	62
114	180	58
121	152	49
115	108	43
110	84	38
109	79	33
117	72	31
117	72	31
112	50	25
111	45	20
113	18	7

Table 12—The 20 destination areas, in Sequoia and Kings Canyon National Parks, with the most campsites within 25 ft (7.6 m) of water

Area number	Area name	Number of sites
9301	Mosquito Lakes	48
6501	Vidette Meadow	37
4602	JMT - S. Fork Kings	37
9303	Eagle Lake	36
6404	Kearsage 1 and 2	36
5701	Woods Lake	32
4202	Middle Dusy Basin	27
6004	Gardiner Pass Lakes	25
6503	JMT - Bubbs	24
3305	Colby Meadow	24
5202	Volcanic Lakes	23
4203	11393 Lakes	22
8902	Columbine Lake	22
8909	Upper Rattlesnake Creek	22
3303	Evolution Meadow	22
5403	Lower Granite Lakes	22
6002	Gardiner Basin	22
9202	Monarch Lakes	21
4502	Palisade Basin	21
8804	Big Five Lakes	21

comparable to an area with five class 3 sites? These weighted values contain no inherent "truth"; they are the product of mathematically inappropriate procedures and a large number of subjective judgments. This should never be forgotten, despite the seductive apparent objectivity of the numbers produced. But if field examinations of a number of areas for which total values have been calculated suggest that the numbers generated do make sense (that areas with comparable total values appear to have comparable impact levels), these values can be a valuable management tool.

3. For a perspective on impact levels for individual sites it can be useful to rank-order sites according to their impact level. Table 11, for example, rank-orders campsites on Minisink Island according to their size. This is an easy means of distinguishing between more heavily and lightly impacted sites. Sites can be rank-ordered within destination areas, larger management units, or the entire wilderness.

Assigning each site a percentile rating can help further to establish relative impact levels for each site. Under the column labeled "percentile" in table 11, values can range from 1 to 100 percent. A site in the first percentile is in the smallest 1 percent of sites in the area; sites in the 100th percentile are among the largest 1 percent of sites. A value of 70 percent indicates that 70 percent of sites are smaller. To evaluate impact levels for different destination or management areas, the number and proportion of sites in categories based on percentiles (for example 20 to 40 percent and 40 to 60 percent) can be calculated. On Minisink Island, for example, only 30 percent of the sites exceed the 50th percentile (for the entire Delaware River corridor) for size; some other destinations along the river have a much higher proportion of large sites.

4. If standards have been established stating maximum levels of impact to be tolerated on campsites, it is important to be able to assess the relationship between current conditions and standards. It would be particularly helpful to be able to "flag" sites or larger areas (depending on how standards are written—for individual sites or larger areas) that either exceed standards or are close to standards. This might amount to simply a list of sites or areas where either of these conditions applies. Where standards are exceeded, increased management is immediately necessary. Where conditions are close to standards, management should be stepped up as soon as possible.

A similar approach can be taken for flagging any other management situation of concern. For example, table 12 lists the management areas in Sequoia and Kings Canyon National Parks with the most campsites within 25 ft (8 m) of water. This could be obtained by flagging management areas with more than 20 sites within 25 ft (8 m). Or it could be obtained by rank ordering management areas according to this variable. Because sites within 25 ft (8 m) of water are targeted for rehabilitation, such a list establishes priorities for such projects.

5. Most of these data will need to be mapped at some point to better understand spatial relationships. Some of the maps that would be useful include maps of all sites in various classes, such as all class 5 sites, maps of all sites that exceed some level, such as a size of 300 m^2, and all sites that exceed standards. Figure 3 shows a map of campsites and impact levels in a portion of the Bob Marshall Wilderness. Very different management approaches will be needed at George Lake (characterized by a large number of lightly impacted sites), Koessler Lake (with only one site, which is severely impacted), and Upper Holland Lake (characterized by many highly impacted sites).

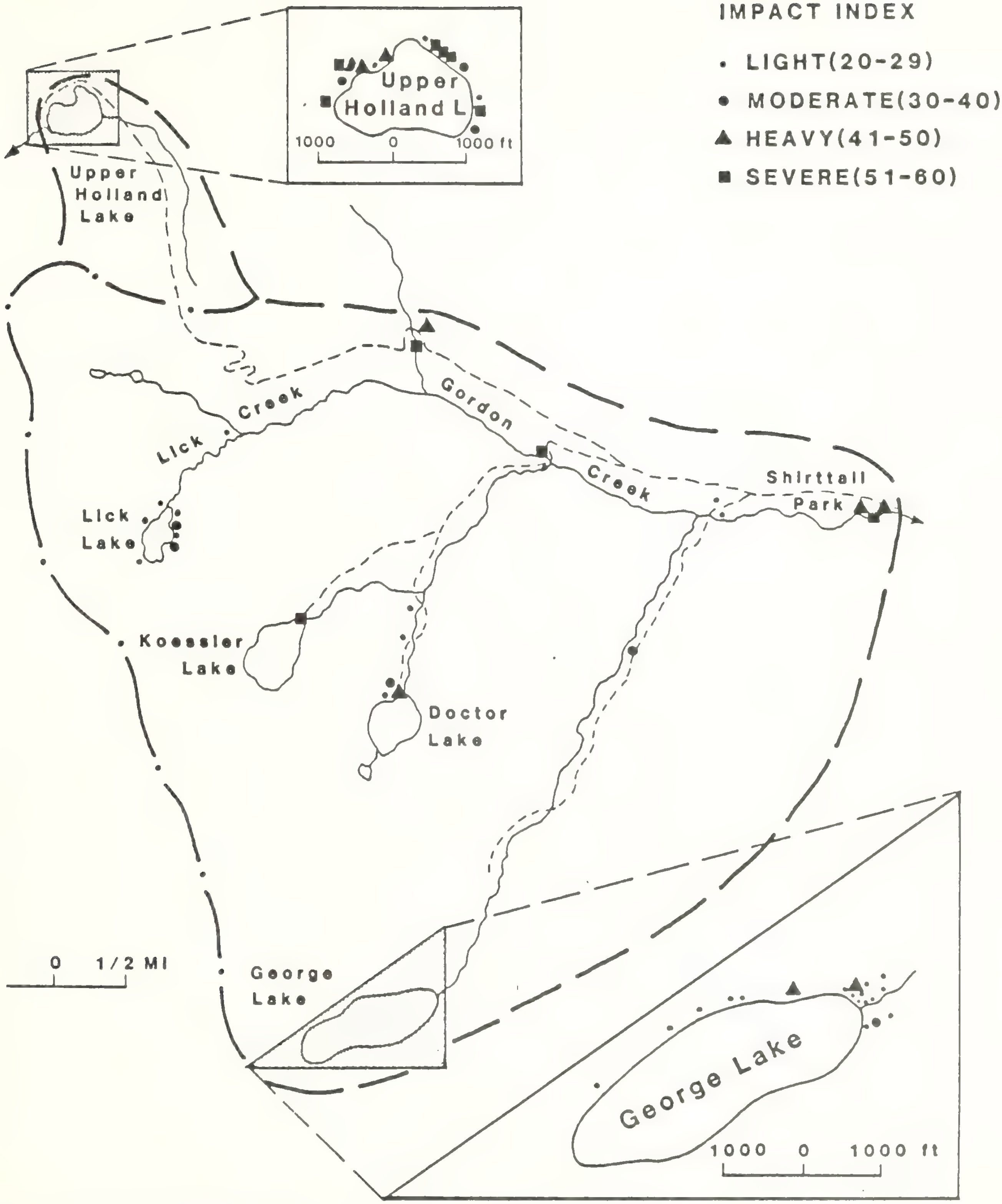


Figure 3—Campsite location of amount and impact in a portion of the Bob Marshall Wilderness. Refer to appendix H for a discussion of the impact index.

The ability to do mapping automatically, using a computer, makes this process much simpler than if data need to be mapped by hand. The data from the inventory of campsites in the Bob Marshall, for example, are being integrated into a Geographic Information System being developed for the area. This will greatly facilitate display and analysis of the data base.

Analysis of Trends

Experience with analyzing data on trends in campsite conditions is more limited. As with analysis of the current situation, it can be useful to be able to recover data on individual sites, to provide summary statistics, to rank-order sites, to flag certain situations, and to have mapping capabilities. The major difference is that the analysis involves comparison of observations taken at more than one time.

1. The ability to easily recover all data for any site, at each observation period, is a useful way to evaluate change on each site. Amount of change can be expressed as the difference between two observations. It can also be expressed as this difference as a percentage of the earlier observation. For example, if the area of the site increased from 400 to 500 m^2, it increased 100 m^2, which is 25 percent. As the number of sites increases, analyzing changes on individual sites becomes increasingly impractical.

2. Summary statistics provide a perspective on amounts of change for the entire area or portions of areas, such as management or destination areas. Medians and ranges are useful statistics for displaying typical changes and variability in response. Table 13 shows changes over 5 years on 16 campsites in the Eagle Cap Wilderness (Cole 1986b). Medians at the two observation periods are provided, as are medians for the difference between these observations and this difference expressed as percent change. Finally, the number of sites that increased or decreased is displayed in order to evaluate how consistent changes were, and the statistical significance of the change is assessed.

Such statistics, in addition to indicating what changes have occurred, can be used to assess differences in amount of change between management areas within a wilderness. Areas with more pronounced changes or a greater proportion of sites experiencing change should be assigned a high priority for management attention.

3. Sites can be rank-ordered according to how much change has occurred since the last observation period. As with the analysis of the current situation, each site's percentile can be determined to gain a perspective on how change compares to what has occurred on other sites. Those sites in the higher percentiles and those areas with a large number of sites in the higher percentiles are the sites and areas with the greatest need for more intensive management.

4. There are a number of situations that might usefully be flagged. Those sites that have deteriorated or improved most might be identified, as might the management areas that have deteriorated or improved most. Other situations that might be flagged include those that still exceed standards, those that have violated standards over the observation period, those that are approaching standards, and those that have improved in relation to standards.

5. Any of these sets of flagged sites could be mapped. New sites that have developed and sites that are no longer there could also be mapped. Finally, it can be useful to classify sites according to level of deterioration or improvement and then map sites in each of these classes.

Automatic Data Processing

Access to computer hardware and software makes it a relatively simple matter to perform a myriad of useful analyses. Manfredo and Hester (1983) have developed a software package, written for Apple computers, that analyzes and graphically presents impact monitoring information. The analyses mentioned above, for campsites at

Table 13—Median change in size and tree damage, over a 5-year period, on 16 campsites in the Eagle Cap Wilderness[1]

Statistic	Camp area	Devegetated core area	Damaged trees	Trees with exposed roots	Felled trees
	m²		*Number*		
Median					
1979	198	86	9.0	3.5	4.0
1984	233	104	7.5	3.5	5.0
Difference	22	5	0	0	1.0
Change (%)	11	10	0	0	35
Number of sites					
Increase	14	10	3	4	8
Decrease	1	5	6	3	4
Significance	<0.001	0.03	0.17	0.26	0.08

[1]Difference is the median difference between 1979 and 1984. Change is difference as a percentage of 1979 values. Positive values indicate an increase between 1979 and 1984. Significance was tested with the Wilcoxon matched-pairs, signed-ranks test.

the Delaware Water Gap, were produced using software developed by Chuck Robbins and Jeff Marion. They used the dBASE III data manager, along with some additional programming, to do most of the analyses just mentioned.

Data base managers make data entry simple, and many of them have built-in capabilities to derive basic summary statistics. With some additional programming it should be a simple matter to develop user-friendly, menu-driven software that can easily perform all needed analyses and then generate maps and graphs to display results.

Research Needs

Because efforts to monitor campsites are still in their infancy, we have little experience with analysis of monitoring data. Experience with trend data is particularly limited. The preceding discussion presented some ideas and, where possible, some examples. We need to evaluate means of analyzing and displaying these data. Once these methods are fairly well established, it should be possible to develop software packages that will simplify the analysis procedures.

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STEP 7. MANAGEMENT APPLICATIONS OF MONITORING DATA

Many of the early attempts to monitor campsites were not very successful because plans for using the data generated were unclear. This is the reason for all the emphasis in step 1 on deciding on your needs and which types of impact are most critical. It is also important, from the start, to have a plan for using the data. Otherwise time may be spent collecting information that is never used and items of importance may be overlooked. Four important uses for monitoring data can be described.

Establishing Management and Budget Priorities

Perhaps the most immediate use of the data is to establish priorities for management projects. The analysis of the current situation will identify places where campsite impacts are particularly severe and followup measures will identify places where conditions are deteriorating greatly. These places should receive a high priority for management attention.

Exactly what situation is most undesirable and deserving of management attention will vary from area to area. At Sequoia and Kings Canyon National Parks, where the policy is to obliterate campsites located within 25 ft (7.6 m) of water, those places with the most sites close to water receive a high priority for management attention. Where severely impacted sites are not tolerated, places with many class 5 sites (or some other measure of severe impact) would be a high priority. Managers who are particularly concerned with the proliferation of impacts might assign highest priority to places with the greatest increase in number of sites. Regardless of management objectives, if the appropriate types of measures are taken, it should be a simple matter to identify places that are in particular need of management attention and, therefore, should receive a high priority in the budgeting process.

Monitoring can also facilitate the budgeting process by more objectively describing the nature and extent of impact problems. Specific problems in specific places can be identified, making it a simpler matter to determine the level of funding necessary to deal with these problems.

Management of Specific Sites

This type of analysis can also be extended to the management of individual sites. It is possible to identify those sites that are currently most heavily impacted, as well as those sites that are deteriorating most. Moreover, as long as data on individual impact parameters have been recorded separately, it will be clear which types of impact are most severe or are deteriorating most. This is important because very different management actions are needed for different types of impact. Damage to trees, for example, is best dealt with through education of campers; total area of the campsite might be dealt with through limits on party size or through site management intended

to make site expansion more difficult; loss or disturbance of organic horizons is inevitable with use, although it might be less severe if campsites were used less frequently. Management responses must be tailored to the particular types of impact that are occurring.

Relationship to Standards

Recently there has been an attempt to make management more objective, explicit, and consistent by using specific statements of objectives to drive management. This approach, described most completely in a process termed "limits of acceptable change" (LAC) (Stankey and others 1985), involves the definition of standards. Standards are precise, usually quantitative, statements of maximum levels of impact that will be tolerated (for example, campsites will be no larger than 1,000 ft²).

Standards are statements of conditions that, at a minimum, will be provided. Existing conditions can be compared with standards to determine where problems exist. A problem, by definition, is a situation where standards are violated. Where problems exist, increased management is required. Conversely, where problems do not exist, management actions that constrain legitimate recreational uses should not be required. Once standards are agreed on, situations where management actions are and are not needed can be agreed on. Often the specific management actions needed are also obvious because the nature and location of problems are quite specific.

Inventory and monitoring are a critical part of this process and most areas will have standards related to campsite impacts. Through a process such as LAC, campsite monitoring is formally integrated into the planning process. This was successfully done in the Bob Marshall Wilderness complex, which will provide the examples in the following discussion.

During early meetings in the planning process, campsite impacts were identified as one of the foremost concerns in the area. Consequently, development of a campsite inventory and monitoring procedure was a high priority. Because the area to be inventoried was 1.5 million acres (0.6 million ha) and there was only a handful of people available to work part time on the inventory, a procedure involving rapid estimates of a number of site characteristics and impact parameters was developed (Cole 1984).

The first issue was to select the types of impact (indicators in the LAC terminology) to write standards for. These were decided on after field trips to identify problem situations, evaluation of public concerns, and analysis of detailed measurements on a sample of 35 campsites (Cole 1983b). Frequent problems in need of management were places with excessive numbers of sites, places with large numbers of highly impacted sites, and individual sites with excessive amounts of barren soil. The specific indicators selected to address these problems were (1) the number of campsites per 640-acre (259-ha) section, (2) the number of moderately and highly impacted campsites per 640-acre (259-ha) section, and (3) the area of barren core on any campsite.

Moderately and highly impacted sites were sites with a summary rating of 30-50 and more than 50, respectively. These summary ratings were derived by rating nine parameters, multiplying these ratings by weights (reflecting the relative importance of each parameter), and summing these products. Refer to appendix H for more detail.

The Bob Marshall Wilderness complex was subdivided into four opportunity classes. Different standards were written for each of these opportunity classes. For example, the standards for maximum number of campsites per 640-acre (259-ha) section are one in opportunity class 1, and 2, 3, and six in classes 2, 3, and 4, respectively. Other standards for opportunity class 1 are no moderately or highly impacted campsites per section and no more than 100 ft² (9 m²) of barren core on any campsite. Analogous standards for opportunity class 4 are no more than three moderately impacted sites and no more than one highly impacted site in any section, and no more than 2,000 ft² (186 m²) of barren core on any campsite.

Whether current conditions violate standards or not can easily be determined from the inventory data. Barren core can simply be read off the form or flagged on a computer data base. The number of sites per section requires mapping and then counting of numbers of sites. The number of moderately and highly impacted sites can be assessed in a similar manner, although it is necessary to first calculate summary impact ratings.

Defining standards provides a specific focus for campsite monitoring, as well as for the entire planning and management process. As increasing numbers of areas adopt this framework, the use of monitoring data in relation to standards is likely to become increasingly important.

Use in Developing Visitor-Use Capacities

Data from campsite inventories have been used to establish visitor use limits at Sequoia and Kings Canyon National Parks. The procedure is discussed in detail by Parsons (1986) and Parsons and Stohlgren (1987). The following discussion is excerpted from those papers.

Sequoia and Kings Canyon National Parks have been divided into 52 backcountry travel zones. Each zone has a daily use capacity, determined largely on the basis of campsite inventory data. Zone capacities are controlled by daily trailhead quotas, established through the QUOTA computer model developed at Yosemite National Park (van Wagtendonk and Coho 1986).

The decision to base zone capacities on campsites reflected a major management objective of maintaining historical use patterns in the Parks. This assures that traditional low-use (and generally low-impact) areas will remain, while recognizing the futility of trying to reduce use levels in traditional heavy use areas, particularly given the long periods required for recovery from impact.

The first step in the process of setting capacities was to count the number of class 3, 4, and 5 campsites in each destination area (termed management area). The number of these sites that were unacceptable (either because they were within 25 ft [7.6 m] of water, within 100 ft [30 m] of

another class 3, 4, or 5 site, or unacceptable for some other reason) was determined and subtracted from the original total. This final number was the maximum number of sites that could be used at one time. Class 1 and 2 sites were not included, although it was recognized that they would continue to be used occasionally.

This estimate of the number of acceptable sites was evaluated by a team of scientists and managers familiar with the area. In many cases it was agreed that more acceptable sites were available than could ever be occupied at one time without exceeding either the peak recorded use or the group's opinion of what use level was appropriate. In these cases, the maximum number of sites was reduced to a level that seemed appropriate, without causing unacceptable crowding or increases in use.

The maximum number of sites was summed for each destination area in each zone to obtain a zone total. These numbers were compared with available information on the number of parties using specific zones during peak use periods. If these numbers exceeded the reported peak use, they were reduced accordingly. The final number of acceptable sites that could be occupied at one time was multiplied by the average party size to obtain the maximum daily number of persons allowed in each zone.

Parsons and Stohlgren (1987) stress that the rationale behind this approach stems from a goal of maintaining existing use and impact patterns. Should objectives stress either more stringent preservation or provision of more recreational opportunities, underlying assumptions would have to be shifted and the procedure would have to be modified. Nevertheless, capacities could still be derived largely from campsite inventory data.

Research Needs

Research could suggest additional ways that monitoring data might be applied to management. Further work on which types of impacts (indicators) are most useful for writing standards would be helpful, as would evaluation of the success of programs that do utilize monitoring data in their management programs.

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APPENDIXES A-K: SELECTED PROCEDURES USED TO MONITOR WILDERNESS CAMPSITES

Appendix A: Photopoint Photography (Adapted From Brewer and Berrier 1984)

The technique requires a referenced and easily relocated camera position from which photographs can be taken periodically for comparison. The first step is to analyze the subject area carefully. Select a camera position that provides the most advantageous perspective (with the available equipment) of the expected change. Photographers on successive photo missions may feel compelled to move the camera slightly to achieve what they feel is a better coverage of the subject. This might result in a loss of information, which could be avoided by properly anticipating what coverage will be necessary as changes occur over time. Documenting the reason for the camera placement when it is not immediately evident may avoid costly changes.

Once a location for the photopoint has been determined, a physical marker should be established. Permanent landmarks such as boulders or other large objects should be utilized when possible. Where landmarks such as these are not available, some kind of stake can be driven flush with the ground surface. Size, weight, and durability are limiting factors. Wood is light, but may deteriorate faster than desired. Objects as small as nails can be used to permit relocation with a metal detector. (This is more appropriate in wilderness.) Any marker should be as inconspicuous as possible to avoid vandalism.

Referencing the photopoint is the next step. Two nearby permanent objects can be used as references, but three are better. Trees are good references and may be marked with numbered aluminum tags. (Note: Tags are not appropriate in designated wilderness.) Identification tag numbers should be recorded along with the bearing and distance from each tree to the photopoint. Sketch maps should be made showing the azimuth from the reference point to the photopoint, the d.b.h. and species of the witness trees, and the general object area in relation to trailheads, shelters, access roads, and so forth (fig. 4). An altimeter reading and slope aspect indication can sometimes help locate the photopoint on topographic maps. A photograph of the area and camera setup is also useful for relocation.

If different cameras are used for successive photos from the same point, film format and lens focal length should be the same. Film of the same type, speed, and spectral sensitivity should be used when possible. A change from black and white to color film can be made with less loss of information if a set of prints is also made from the color negatives or slides for the first year of comparison. The time of day should be duplicated as closely as possible to avoid shadows in different positions. The photos should also be taken during the same time of year (the size of the "window" of duplication days will vary according to the needs of the study). Carrying copies of the original photos into the field can facilitate accurate reproduction.

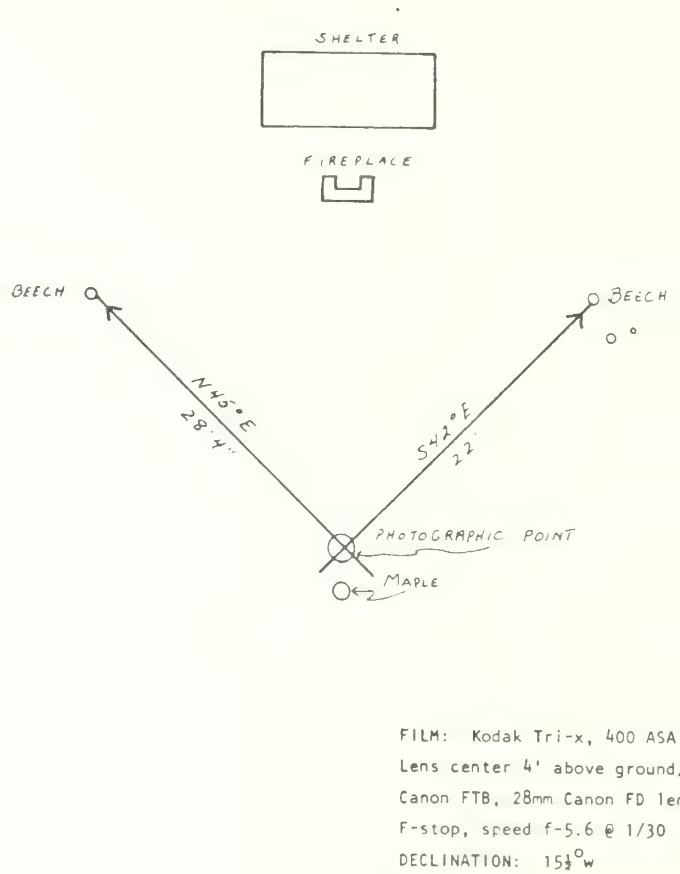


Figure 4—Sketch map referencing a photopoint.

Appendix B: The Frissell Condition Class System (Modified From Frissell 1978)

After locating campsites on a map of the area, assign each campsite a rating between 1 and 5, using the following definitions:

Class 1—Ground vegetation flattened but not permanently injured. Minimal physical change except for possibly a simple rock fireplace.

Class 2—Ground vegetation worn away around fireplace or center of activity.

Class 3—Ground vegetation lost on most of the site, but humus and litter still present in all but a few areas.

Class 4—Bare mineral soil widespread. Tree roots exposed on the surface.

Class 5—Soil erosion obvious. Trees reduced in vigor or dead.

Appendix C: The Sequoia-Kings Canyon Campsite Class System (Adapted From Parsons and MacLeod 1980; Parsons and Stohlgren 1987)

Campsites are located on an area sketch map (fig. 5). Then each campsite is rated on the basis of eight criteria (fig. 6). A rating between 1 and 5 is assigned to each factor that applies. These ratings are summed and divided by the number of factors used. For example, if there are no trees on the site, this criterion is ignored and the sum of rankings is divided by 7, instead of 8. This mean, rounded to the nearest integer, is the campsite class. Figure 7 shows the field inventory form used for eight of the campsites around Lake Reflection.

Additional instructions that might not be self-explanatory from the criteria and rating factors in figure 6 include:

1. Density of vegetation is evaluated by comparing the extent of vegetative ground cover on the campsite with that on environmentally similar but unimpacted areas off the site.

2. Composition of vegetation also involves a comparison with an undisturbed area.

3. Total area of the campsite is an estimate of the area affected by trampling on the site.

4. Barren core area is an estimate of the area on which trampling has removed all vegetation; organic horizons may or may not still be present.

5. Social trails are the informal trails that develop between the campsite and the trail, water, and other campsites. It will be necessary to define what constitutes a well-developed, as opposed to a discernible, trail.

6. Mutilations refer to trees; this factor will not apply in nonforested areas. Mutilations include carvings, ax marks, and nails. More than one mutilation can occur on one tree. A definition should be developed for what constitutes a highly obtrusive mutilation and a decision must be made about how far offsite to count trees.

In addition to the campsite impact class, descriptive information on the local environment is recorded on the inventory form (fig. 7). The distance to water and the number of class 3, 4, and 5 sites within 100 ft (30 m)—a measure of campsite crowding—are also recorded. If the site is not acceptable, a potential large group site, or in need of obliteration, this is noted, as are any recommended management actions.

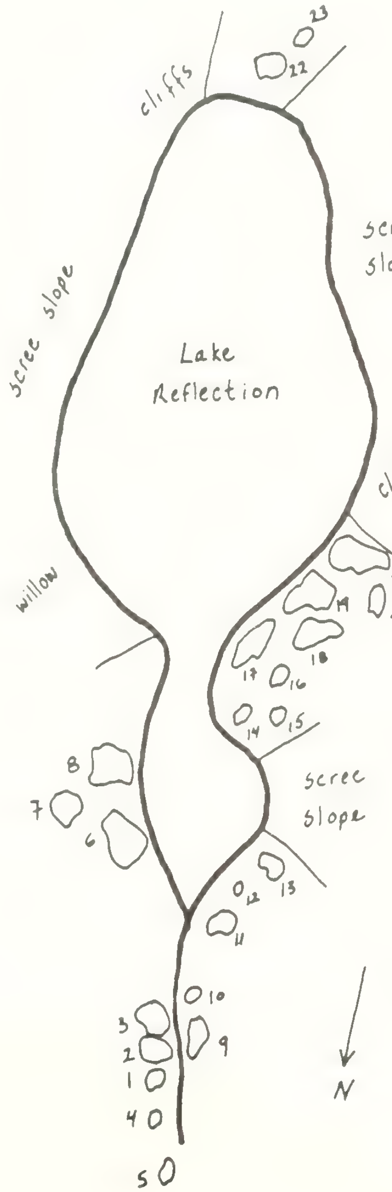


Figure 5—Example of a field map showing the campsites around Lake Reflection.

Density of Vegetation
(With respect to surrounding vegetation):

1 - same as surroundings
3 - moderately less dense than surroundings
5 - considerably less dense than surroundings

Composition of Vegetation
(With respect to surrounding vegetation):

1 - same as surroundings
3 - moderately dissimilar
5 - significantly dissimilar

Total Area of Campsite

1 - less than or equal to 20 ft^2 (2 m^2)
2 - 21 to 100 ft^2 (2 to 9.3 m^2)
3 - 101 to 500 ft^2 (9.4 to 46 m^2)
4 - 501 to 1,000 ft^2 (46.1 to 93 m^2)
5 - greater than 1,001 ft^2 (93 m^2)

Barren Core Area

1 - absent
2 - 5 to 50 ft^2 (0.5 to 4.6 m^2)
3 - 51 to 200 ft^2 (4.7 to 18.6 m^2)
4 - 201 to 500 ft^2 (18.7 to 46 m^2)
5 - greater than 501 ft^2 (46 m^2)

Campsite Development

1 - windbreaks and paraphernalia absent; trash and seats minimal; firerings absent or scarce
2 - trash, windbreaks, seats, and firerings minimal; paraphernalia absent
3 - trash, windbreaks, seats mostly moderate; firerings mostly minimal; paraphernalia minimal
4 - trash, windbreaks, seats, firerings, and paraphernalia mostly moderate; some heavy
5 - trash, windbreaks, seats, firerings, paraphernalia mostly heavily developed

Litter and Duff

1 - trampling barely discernible; some needles broken; scattered cones
2 - moderately trampled; needles broken, compacted; few cones
3 - heavily trampled, clumped, pulverized; cones absent
4 - litter ± absent, pulverized, ground into soil
5 - litter, cones, and duff completely absent

Social Trails

1 - none
2 - 1 trail discernible
3 - 2 trails discernible
4 - 1 to 2 trails well developed, or 3 or more trails ± discernible
5 - 3+ trails well developed

Mutilations

1 - none
2 - 1 to 2
3 - 3 to 5
4 - 6 to 10 or 1 to 2 highly obtrusive
5 - 11+ or 3 ± highly obtrusive

Figure 6—The criteria and rating factors used to inventory campsites in Sequioa and Kings Canyon National Parks.

CAMPSITE FIELD INVENTORY FORM

Date 9/3/77

Management Area LAKE REFLECTION Zone 67 Elevation 10,005

Landform LAKE BASIN

Capability: Potential 20% Currently Used 20%

Overstory/Cover LP-FT / 50%

Meadows NOT SIGNIFICANT Fuels Rating SCARCE

Comments NO END LP-FT FOREST 50% COVER;

Campsite Number (on map)	Campsite Class	Ecological Type Overstory	Understory	Site Pot.	Dist. to H_2O	Crowding 3,4,5's	Comments
1	2	LP OPEN	BARREN	OBLIT.	4	–	2 FIRE RINGS
2	3	LP INT	BARREN	OBLIT	4	–	1 RING/GRILL
3	3	LP OPEN	GRASS <10%	OBLIT	4	–	2 RINGS
4	1	ROCK	ROCK	–	2	–	–
5	2	LP INT	BARREN	–	3	–	1 RING
6	5	LP INT	RIBES	OBLIT	4	–	3 RINGS
7	2	LP CLOSED	BARREN	–	1	–	–
8	5	LP CLOSED	GRASS/HERBS	–	3	–	3 RINGS

Application of Rating Factors for Campsite Class Determination:

Camp Site	#1	#2	#3	#4	#5	#6	#7	#8
Density	3	3	3	1	3	5	3	5
Composition	1	3	3	1	1	5	1	5
Total Area	3	4	5	1	2	5	2	5
Barren Core	3	3	3	1	2	5	3	5
Camp Development	2	4	3	2	3	5	2	5
Litter & Duff	1	3	2	1	1	5	2	4
Social Trails	1	3	2	1	2	4	1	5
Mutilations	1	2	2	1	2	5	1	5
Mean Rating or Campsite Class	2	3	3	1	2	5	2	5

Figure 7—Example of the data collection form used to inventory campsites around Lake Reflection.

Appendix D: The Eagle Cap Method of Measurements on Permanent Sampling Units (Modified From Cole 1982)

Campsite Measurements—Locate a center point in a position that will permit easy measurement of the site. Mark it, for later relocation, with a large buried nail. Reference the location of the center point, noting azimuth and distance from two (or preferably three) landmarks. (See discussion of referencing in appendix A.)

Measure the distance for 16 azimuths (N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, and NNW) from the center point to the first significant amount of vegetation (defined, for the Eagle Cap study, as at least 15 percent cover in a 1.09-by 3.28-ft [0.33- by 1-m] quadrat oriented perpendicular to and bisected by the measuring tape). Be sure to note whether true or magnetic north was used. These intercepts define the boundary of the devegetated central core of the campsite (the bare area in fig. 8). Also measure the distance to the edge of the campsite (where trampling is no longer evident) and record these 16 transect intercepts. If an untrampled "island" is encountered in any direction, note the distance to the "island" and the reentry onto the campsite, as well as the campsite boundary. These intercepts define the campsite boundary, as well as the area of the "island" which is to be subtracted from the area of the campsite (fig. 8).

In the case of both camp and bare area, boundaries are approximated by drawing straight lines between adjacent intercepts. Note in figure 8 that while this boundary differs from the actual campsite boundary, the total camp area is about the same. To calculate area, intercepts and connecting lines are plotted on a radial map. Figure 9 shows the campsite and "island" boundaries on such a map. Use a planimeter to calculate the area of total campsite, "islands," and bare area. Subtract the "island" area from the total campsite area to obtain the camp area. A simpler method is to simply calculate the area of each of the 16 triangles defined by adjacent transects (fig. 8) and sum these. The area of each triangle is the length of each of the two transects times 0.383 (the sine of the 22.5 degree angle) divided by 2. In this case, ignore the "island" in calculating these areas of triangles, estimate the area of the "island" in the field, and subtract this value from the sum of the triangles. Refer to appendix J for further discussion of this technique.

Place flagging temporarily at each of the 16 points along the edge of the campsite. Straight lines drawn between these points define the campsite on which replicable measurements will be taken. Count all tree reproduction, defined for the Eagle Cap study as trees more

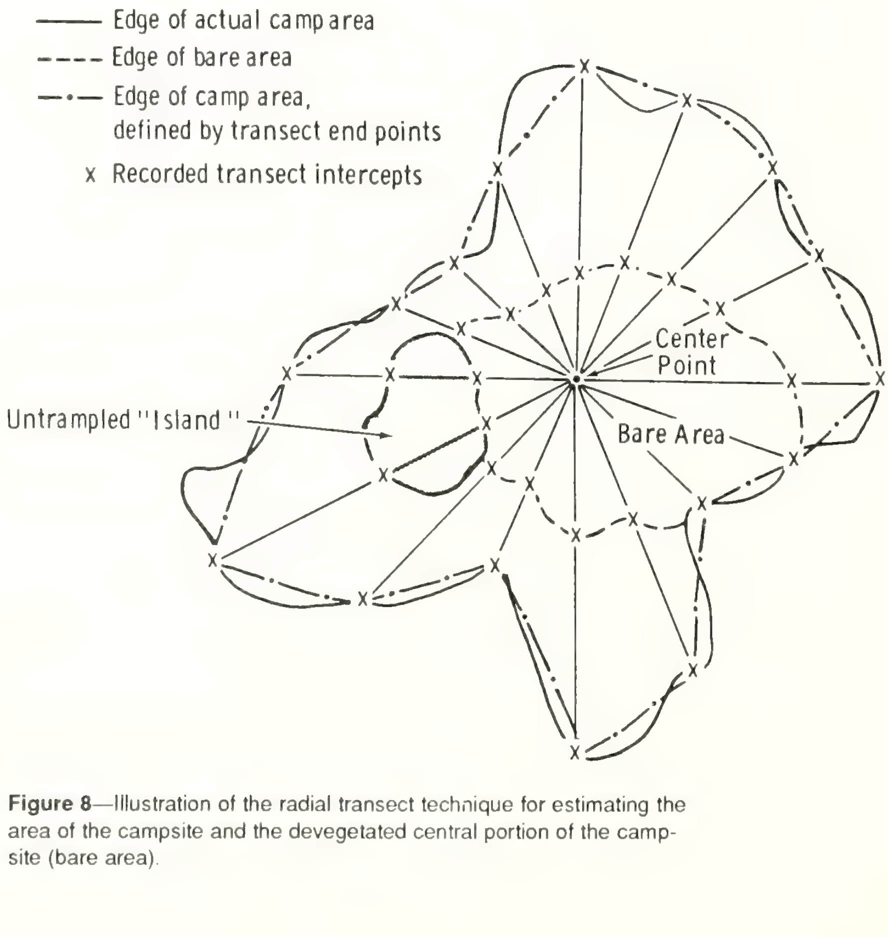


Figure 8—Illustration of the radial transect technique for estimating the area of the campsite and the devegetated central portion of the campsite (bare area).

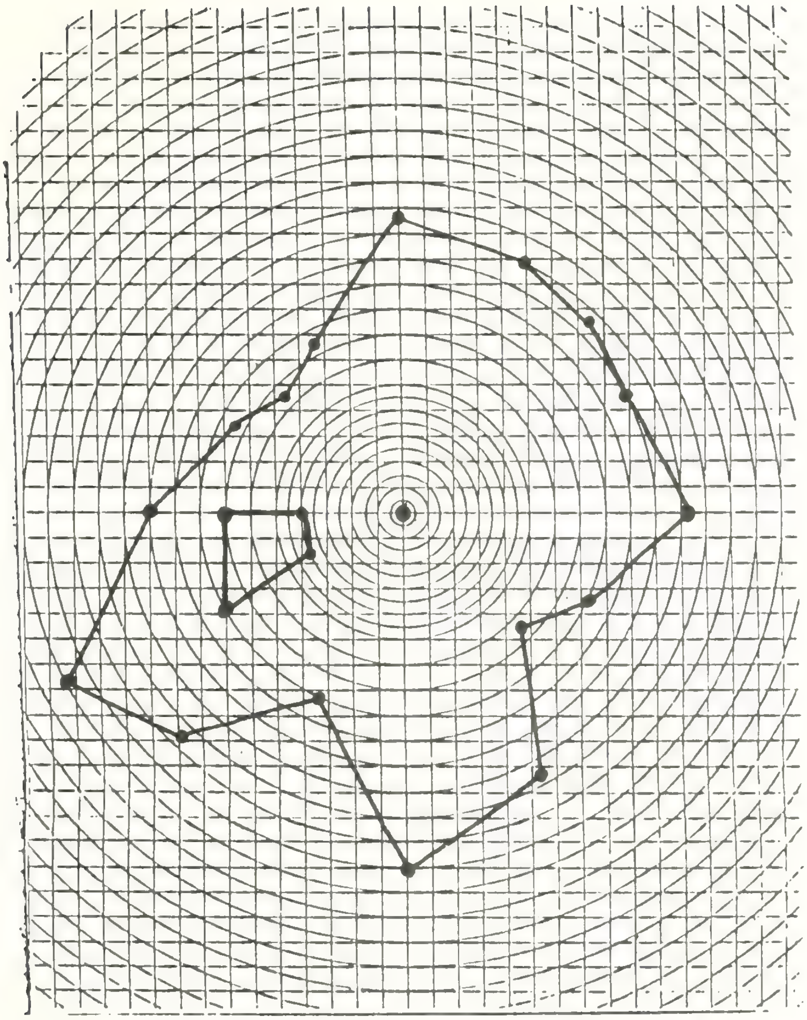


Figure 9—Example of a radial map used to calculate the area of the campsite in figure 8. Concentric circles are 1 m apart (0.5 m apart within 5 m of the center point). Each square is 1 m^2.

than 6 inches (15 cm) and less than 4.5 ft (140 cm) tall, within this area. Exclude reproduction in untrampled "islands."

Within this same area, count all trees and then note how many are damaged. The types of damage noted in the Eagle Cap study were felled trees, exposed roots, trunk scars, cut branches, nails, and other minor injuries. Another approach would be to use damage categories, as Marion and Merriam (1985) did (see section on tree damage in step 2).

Take additional measurements in quadrats established along four transects that originate at the center point and extend to the edge of the site. Randomly select the azimuth of the first transect (from random numbers between 1 and 90). The azimuth of each successive transect is 90 degrees greater than the azimuth of the previous transect. Bury nails at the end (campsite boundary) of each transect.

Locate about 15 quadrats along these transects. The number on each transect should be roughly proportional to the relative length of each transect. The distance between quadrats on any transect should decrease with distance from the center point (fig. 10). This avoids sampling more heavily toward the center of the site. Measure only quadrats that fall entirely within the campsite.

Within each quadrat estimate the percentage cover of understory vegetation, exposed mineral soil, exposed rock and tree roots, and trunks. Estimate the cover of organic litter, whether it is under vegetation or not (this is an improvement over the technique used in the Eagle Cap). Finally, estimate the cover of all plant species. In the Eagle Cap study, all mosses and all lichens were estimated as a group. Coverage was estimated in 10 percent coverage classes between 10 and 100 percent or to the nearest percentage if cover was 10 percent or less.

Within each quadrat, measure the depth of the organic horizons and take a reading of penetration resistance, with a pocket soil penetrometer. In the Eagle Cap study, four sets of soil samples, bulk density, and infiltration rate measurements were taken. Given the variability of results, this number of samples was probably too small. Read the section in step 2 on impacts to the mineral soil for a discussion of these techniques.

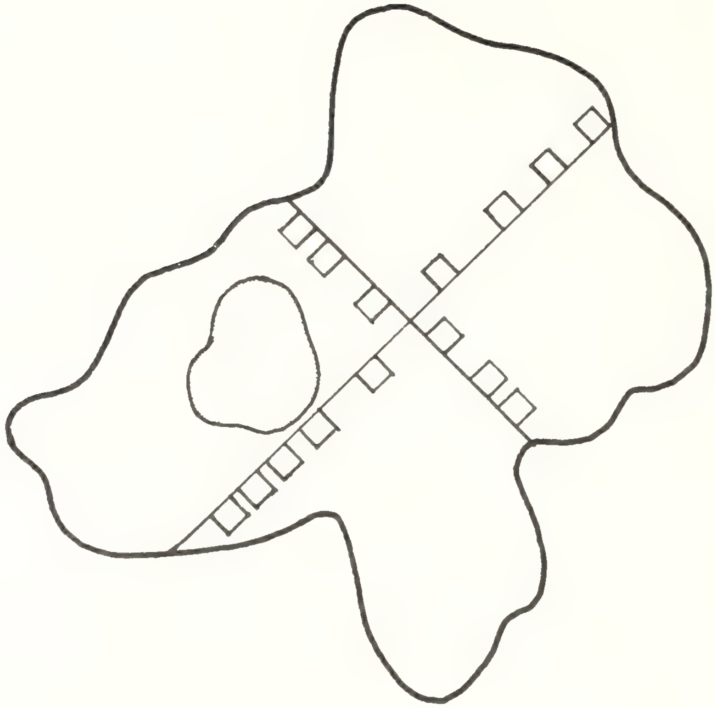


Figure 10—Location of quadrats for sampling ground cover parameters on the campsite in figure 8.

Control Sites—Take a set of comparable measurements on control sites; amount of impact can then be estimated as the difference between conditions on the campsite and on an undisturbed control. Locate controls as close to the campsite as possible, in places that are undisturbed but where the topography, rockiness, tree canopy cover, and understory species are similar to the campsite. Often the understory composition has to be compared to what is surviving in protected places on the campsite.

Bury a nail at the center point of the control and reference it to landmarks, as well as to the campsite. In the Eagle Cap study, controls were generally circular, with an area of 1,000 to 2,000 ft^2 (100 to 200 m^2). Estimate the percent cover of understory vegetation, exposed mineral soil, exposed rock and tree roots and trunks, organic litter, whether it is under vegetation or not, and of all plant species. In the Eagle Cap study, a single cover estimate for the entire control was made, rather than estimating cover in quadrats, as was done on the campsite. This was more rapid and seemed justified because precision was less of a concern on controls. As on campsites, cover was estimated in 10 percent coverage classes between 10 and 100 percent or to the nearest percent if cover was 10 percent or less.

Take measures of penetration resistance, organic horizon thickness, bulk density, and infiltration rates in regularly distributed locations on the control. The number of samples should be the same as the number on campsites.

Finally, count tree reproduction in a circle, centered at the center point, with an area of 538 ft^2 (50 m^2). Appropriate areas for control plots will vary between regions and impact parameters.

Appendix E: The Sequoia Method of Measurements on Permanent Plots (Modified From Stohlgren and Parsons 1986)

Establish a 32.8- by 32.8-ft (10- by 10-m) sampling unit, aligned along compass directions and located such that most of the campsite is included. Place permanent markers (such as buried nails) at each corner and reference at least one corner. (Refer to the appendix section on photopoints for a discussion of referencing.) Place temporary stakes at 3.28-ft (1-m) intervals along each side. Connect stakes with string to form a 100-cell grid of 10.76-ft^2 (1-m^2) sections.

Subdivide each section mentally into four 2.69-ft^2 (0.25-m^2) plots. Stratify each of these plots subjectively into core, intermediate, and periphery (essentially control) plots. Core plots are generally in the center of the site and show nearly complete loss of vegetation and organic matter and continuous disturbance of the mineral soil. Intermediate plots show notable but less substantial damage (more vegetation cover, less litter and duff pulverization, and pockets of intact sod). Periphery plots appear to be unimpacted and border the site. Map each zone (see fig. 11) and take a subsample of five to 10 plots randomly from each zone.

In each plot, estimate the foliar cover of each plant species to the nearest 5 percent (to the nearest 1 percent if cover is less than 5 percent). Collect five to 10 soil samples from each zone to analyze bulk density, soil moisture, soil texture, organic matter content, pH, and chemistry.

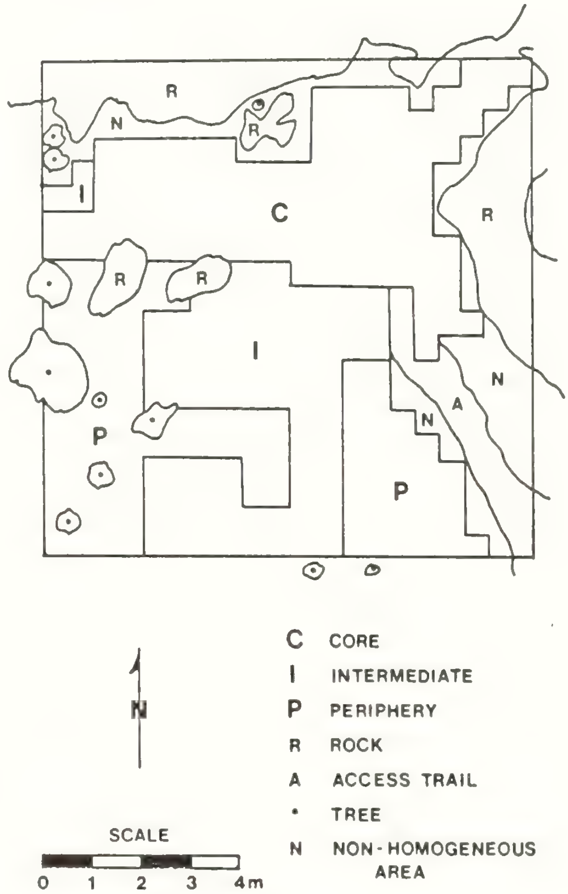


Figure 11—Map of zones within the 1,076-ft^2 (100-m^2) sampling area on campsites.

Appendix F: The Olympic Bare Ground Technique (Adapted From Schreiner and Moorhead 1979)

The first step is to map all individual campsites within groups of campsites. For each site, fill out a human impact inventory form (fig. 12). The impact data on the form are found in items 31, 32, and 35 through 38, estimated as follows:

Item 31: Note whether or not horse feces are present.

Item 32: Note the number of horse trample areas (trampled depressions around trees where horses have been tethered) within 100 ft (30 m) of the site.

Item 35: Count the number of social (informal access) trails that enter the site.

Item 36: Note whether or not erosion is obvious on the site.

Item 37: Measure the distance from a temporary center point to the first vegetation (this must be defined in an agreed-upon manner) in eight directions (N, NE, E, SE, S, SW, W, NW). Note the mean of these eight radii in the seven classes provided—no bare ground; 1-2 ft (0.3-0.6 m); 2.1-4 ft (0.7-1.2 m); 4.1-6 ft (1.3-1.8 m); 6.1-8 ft (1.9-2.4 m); 8.1-10 ft (2.5-3.0 m); and 10.1 ft (3.1 m) and longer.

Item 38: Record each tree on the site, by species, noting diameter and the extent of damage.

Finally, draw a sketch map of the site, to scale. The map is drawn on either a 1- by 1-m grid or a 2- by 2-m grid. This map serves as a baseline for the size of the bare area, the location of social trails, downed logs, and the approximate location of the center point used to determine mean bare radius.

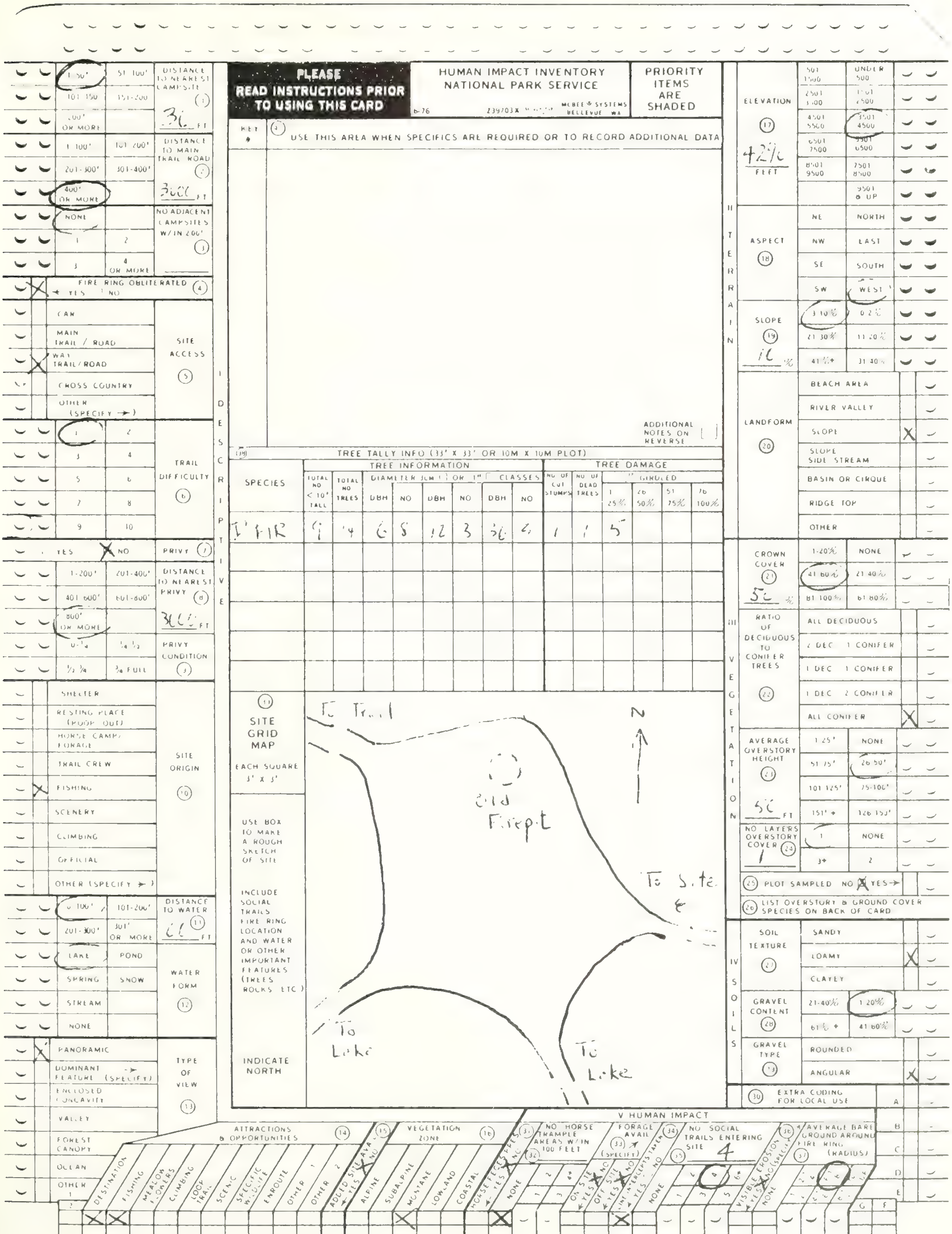


Figure 12—Front side of a completed campsite inventory edge-punched card used to monitor campsites at Olympic National Park.

Appendix G: The Great Smoky Mountains Areal Measurement Technique (Adapted From Bratton and Others 1978)

Little of the information on the campsite monitoring form (fig. 13) concerns impacts. Most of it provides information on environmental characteristics, attractions, developments, and the water source. The primary impact information is contained in the section on site dimensions. For each type of disturbance, measure two dimensions and then multiply these to obtain an area measurement. The disturbances measured are bare rock, mud, slope erosion, bare soil, leaf litter (vegetation removed by trampling), trampled vegetation, firewood clearing, tree damage, and trash dispersal. Quantify trash dispersal, tree damage, and firewood clearing in terms of maximum distances from the center of the site. Quantify other disturbances by summing the areas of disturbed patches. Total disturbance is the maximum areal extent of human impact at the site. In addition, trash level, sanitation, and vegetation damage are rated in classes from good or no damage to bad or high damage.

#____ Name ____________ Quad ________ Coordinates ________ ________

Location ______________________________

Type ______________________________

Forest type ______________________________ Open canopy? ______

Understory ______________________________ Exotics? ______

Site dimensions	1	2	Area
Bare rock			
Mud			
Bare soil			
Leaf litter			
Trampled veg			
Firewood clear			
Tree damage			
Undrained			
Slope erosion			
Trash			
TOTAL DIST			
Hog damage			
Horse damage			

Topography	
Slope site	
Aspect, site	
Slope above	
Slope below	
Aspect envir	
D below top	
Convexity si	
Convexity en	
Moisture	
Drainage	
Elevation	
Spring	
Stream	
Seep	

Water	
Spring#	
Creek(size)	
Lake	
Pipe	
Flow	
Erosion above	
Silt	
Mud(area)	
dis camp	
pos camp	
dis erosion	
dis privy	
pos privy	
dis human	
dis animal	

Attractions:
Fruit plants ____
Wild flowers ____
Big trees ____
Balds ____
Views ____
Waterfalls ____
Fishing ____
Poaching ____
Horse camp ____
Tower ____
Shelter ____
Near cmpgrd ____
Near viscen ____
Major access ____
Near road ____
AT near ____
Remote ____
Private ____
Dry ____
Other:

Developements:
Shelter ____
Bear fence ____
Shelter frame ____
Tent space ____
Privy ____
Fireplace ____
Picnic tables ____
Bear barrels ____
Firepits ____
Hitchracks ____
Camp circle ____
Sign camp ____
Sign water ____
Sign trail ____
Other:

Rating:
Frequency use ____
Carry capacity ____
Trash level ____
Firewood level ____
Mud and dirt ____
Sanitation ____
Vegetation dam ____
Placement ____
Drainage ____
Maintenance ____

Site future, why? ________________

____

____

____

Suggested improvements and hazard reduction:

General comments:

Last rain ______
Leaf fall ______
Observer ______
Date __ __ __

Figure 13—Form used to monitor campsites at Great Smoky Mountains National Park.

Appendix H: The Bob Marshall Rapid Estimation Procedure (Adapted From Cole 1983a, 1984)

The information on one side of the form consists of locational and environmental information (fig. 14a). The impact data are included on the other side of the form (fig. 14b). Instructions for filling out this side are as follows:

Item 19: Using the five coverage classes on the form, estimate the percent coverage of the live understory vegetation. Do not include dead vegetation, duff, trees, tree seedlings, or shrubs taller than a person. Estimate cover for the entire campsite.

With a large campsite, it may help to divide the site into equal quarters; estimate the percentage cover of each quarter and take the average. It may also help to visually cluster all vegetation into one part of the site and estimate what percentage of the site would be covered. Try to select one coverage class decisively. If you cannot, circle your best estimate and note the other coverage class it might be.

Make the same estimate of vegetation cover on a nearly unused site similar—except for the impact—to the campsite. The idea here is to select a site that is similar to what the campsite probably looked like before it was used. Choose a site that is similar to the campsite in terms of rockiness, slope, aspect, overstory composition and cover, and understory species composition. Protected plants around the base of trees or rocks can provide hints about species composition.

Item 20: Using the same five coverage classes, estimate the percentage of the campsite without either live vegetation or duff—the percentage on which mineral soil is exposed. In many cases, a thin layer of disturbed needles, leaves, or wood chips is scattered about with mineral soil showing through. Consider these areas to be exposed soil.

Make the same estimate on the comparative area. In practice it will be easiest to estimate both vegetation cover and mineral soil exposure on the campsite, select the comparative area, and make the same estimates there.

Item 21: Using the information in item 19, record the difference in vegetation cover class between campsite and comparative area. If there is no difference (for example, if both campsite and comparative area are class 4, 51-75 percent), circle rating 1. If coverage on the campsite is one class less than on the comparative area (for example, if the campsite is class 3, 26-50 percent, and the comparative area is class 4, 51-75 percent), circle 2. If the difference is greater, circle 3.

Item 22: Using the information in item 20, record the difference in mineral soil coverage class between the campsite and comparative area. In this case, ratings of 2 and 3 are given when mineral soil is one, or more than one class higher on the campsite, respectively.

Item 23: Count the total number of damaged trees on the campsite, the area visible from the campsite, and any stock holding areas. Never count the same tree on more than one site. Damaged trees include stumps that show cut marks, scarred trees, and trees with nails in them. Trees with lower branches cut off for firewood are not included. (Ignore the estimate of percentage of trees; this information is not necessary.) If no trees were damaged, rate the site 1. If one to eight trees were damaged or if one to three trees were felled or had bad scars (scars larger than 1 ft^2 [929 cm^2]), rate the site 2. If more trees are damaged, badly scarred, or felled, rate the site 3.

Item 24: Count the number of trees with exposed roots on the same area as for tree damage. Exposure should be pronounced, extending at least 1 ft (0.3 m) from the tree trunk. It should also be the result of trampling—not the result of a root running over a rock, for example. Assign a rating of 1 (no trees with exposed roots), 2 (one to six trees), or 3 (more than six trees).

Item 25: Assign the site a rating of 1 if there are no facilities—not even a firering. A fire site is considered a ring only if the ring of stones is there; if they have been scattered, it is a fire scar (see item 26) but not a firering. If there is only one firering, primitive log seats (without sawed off ends), or both, assign the site a 2. If there is more than one firering, or if there are any more elaborate facilities, such as constructed seats, shelves, hitchrails, corrals, toilets, and so forth, assign the site a 3. If the facilities are to be removed, rate the site as it was found and then note in item 31 what actions were taken.

Item 26: Count the number of fire scars on the site, including any firerings as fire scars. Assign the site a 1 if there is only one fire scar and essentially no evident litter, stock manure, or human waste on the campsite. Assign the site a 2 if there is more than one fire scar or if litter or stock manure is evident. If litter or stock manure is "all over the place," or if there is any evident human waste, assign the site a 3.

Item 27: Social trails are the informal trails that lead from the site to water, the main trail, other campsites, or satellite sites. Discernible trails are trails that you can see but that are still mostly vegetated. Well-worn trails are mostly devegetated. Count the total number of trails, regardless of whether they are discernible or well worn. Assign the site a 1 if there is only one discernible trail and no well-worn trails. Assign a 2 if there are two or three discernible trails or one well-worn trail. Assign a 3 if there are more than three discernible trails or more than one well-worn trail.

Item 28: Estimate the square footage of the disturbed campsite and any satellite or stock holding areas. The disturbed area can usually be identified by either shorter or no vegetation in comparison to the periphery of the site. Where there is no vegetation naturally and no other evidence of disturbance to identify the edge of the site, place an N/A in the estimated area space and assign a rating of 1. This may also be necessary on lightly used sites where little vegetation loss is evident.

BOB MARSHALL - GREAT BEAR - SCAPEGOAT WILDERNESS COMPLEX - CAMPSITE INVENTORY

GENERAL SITE DESCRIPTION

(1) SITE NUMBER: 82

(2) UTM COORDINATES: 12 [illegible] E [illegible] N

(3) USGS QUADRANGLE: [illegible]

(4) DATE CODED: [illegible] (Month) [illegible] (Day) [illegible] (Year)

(5) CODED BY: (Name) [illegible]

(6) ELEVATION: (To nearest 100 ft) [illegible]

(7) VEGETATION: (Circle one)

1 - Closed forest 3 - Nonforested, densely vegetated

2 - Open forest 4 - Nonforested, sparsely vegetated

Dominant species [illegible]
Habitat type, if known [illegible]

(8) LANDFORM: (Circle one)

1 - Floodplain 2 - Other valley bottom 3 - Cirque basin

4 - Sideslope 5 - Ridgetop 6 - Other ____

(Do in office)
(9) DISTANCE TO CLOSEST TRAILHEAD: ____ (miles)

(10) DISTANCE TO CONSTRUCTED TRAIL: 100 (feet)

Screening: 1 - Complete
(circle one) 2 - Partial
3 - None

Maintained: 1 - Yes
(circle one) 2 - No

(11) DISTANCE TO WATER: 200 (feet)

Type: 1 - River/creek 3 - Spring
2 - Lake 4 - Other ____

(12) DISTANCE TO CLOSEST CAMPSITE: 150 (feet)

Screening: 1 - Complete
(circle one) 2 - Partial
3 - None

(Do in office)
(13) NUMBER OF OTHER CAMPSITES WITHIN 1/4 MILE: ____

(14) MAXIMUM PARTY SIZE ACCOMMODATED: (Circle one)

1 - 1-2 3 - 7-10 5 - more than 15

2 - 3-6 4 - 11-15

(15) TYPE OF USE: (Circle as many as apply)

1 - Foot 3 - River

2 - Stock 4 - Outfitter

(16) CLOSEST FIREWOOD SOURCE: (Circle one)

1 - One-site 3 - 100-300 feet 5 - >1/4 mile

2 - <100 feet 4 - 300 ft-1/4 mile

(17) CLOSEST FORAGE SUPPLY: (Circle one)

1 - On-site 3 - 100-300 feet 5 - >1/4 mile

2 - < 100 feet 4 - 300 ft-1/4 mile

(18) FACILITIES: Present X Absent ____
(If present, write number of each type in blank.)

1 - Fire ring 2
2 - Primitive seat 4
3 - Constructed seat ____
4 - Table/shelf/counter ____
5 - Meat rack ____
6 - Hitchrail 1
7 - Corral ____
8 - Toilet ____
9 - Other ____

a

Figure 14—The front (a) and rear (b) sides of a completed form used to inventory campsites in the Bob Marshall Wilderness complex.

IMPACT EVALUATION	ON CAMPSITE			ON UNUSED COMPARATIVE AREA		
(19) VEGETATION COVER: (Be sure to compare similar areas, same species, slope, rockiness, and canopy cover)	1 - 0-5% 2 - 6-25%	3 - 26-50% 4 - 51-75%	5 - 76-100%	1 - 0-5% 2 - 6-25%	3 - 26-50% 4 - 51-75%	5 - 76-100%
(20) MINERAL SOIL EXPOSURE: (Percent of area that is bare mineral soil)	1 - 0-5% 2 - 6-25%	3 - 26-50% 4 - 51-75%	5 - 76-100%	1 - 0-5% 2 - 6-25%	3 - 26-50% 4 - 51-75%	5 - 76-100%

Rating (Circle one category)

	1	2	3	Calculation of impact index (do in office)
(21) VEGETATION LOSS:	(no difference in coverage)	(Difference one coverage class	(Difference two or more coverage classes)	
(22) MINERAL SOIL INCREASE:	(No difference in coverage)	(Difference one coverage class)	(Difference two or more coverage classes)	
(23) TREE DAMAGE: No. of trees scarred or felled [illegible] % of trees scarred or felled [illegible] (est.)	(No more than broken lower branches)	(1-8 scarred trees, or 1-3 badly scarred or felled)	(> 8 scarred trees, or >3 badly scarred or felled)	3 × 3
(24) ROOT EXPOSURE: No. of trees with roots exposed 5 % of trees with roots exposed 25 (est.)	(None)	(1-6 trees with roots exposed)	(> 6 trees with roots exposed)	3 × 2 =
(25) DEVELOPMENT:	(None)	(1 fire ring with or without primitive log seat)	(> 1 fire ring or other major development)	1 × 1 = 1
(26) CLEANLINESS: No. of fire scars 2	(No more than scattered charcoal from 1 fire ring)	(Remnants of >1 fire ring, some litter or manure)	(Human waste, much litter or manure)	1 × 2 = 2
(27) SOCIAL TRAILS: No. of trails 4	(No more than 1 discernible trail)	(2-3 discernible, max. 1 well-worn	(> 3 discernible or more than 1 well-worn)	2 × 2 =
(28) CAMP AREA Estimated area 1600 (ft^2)	(< 500 ft^2)	(500-2000ft^2)	(> 2000 ft^2)	4 × 2 =
(29) BARREN CORE CAMP AREA: Estimated area 500 (ft^2)	(< 50 ft^2)	(50-500 ft^2)	(> 500 ft^2)	× 3 =

(30) PHOTO RECORD 2-16

(31) COMMENTS: (Details about location of site, impacts, management suggestions, etc.)

[illegible] little change in management

(32) IMPACT INDEX [illegible]

Figure 14 (Con.)

b

Visualize the site as a circle, a rectangle, or some combination of these geometric figures. Pace off the appropriate dimensions. Calculate area and assign a rating of 1 (<500 ft^2 [<46 m^2]), 2 (500-2,000 ft^2 [46-186 m^2]), or 3 (>2,000 ft^2 [>186 m^2]).

Item 29: Using geometric areas and pacing, estimate the area without any vegetation. Bare area may or may not be covered with duff. Areas with scattered vegetation are not counted as bare area. Lump together in one measure all bare areas on the campsite, including the area around the fire, as well as any bare tent areas, if applicable. If the bare area extends off the campsite into neighboring undisturbed areas—in other words, if the area is devoid of vegetation naturally—write N/A in the estimated area space and assign a rating of 1. If the bare area is less than 50 ft^2 (5 m^2), 50-500 ft^2 (5-46 m^2), or more than 500 ft^2 (>46 m^2), assign ratings of 1, 2, or 3, respectively.

Item 32: The impact index is either the sum of the ratings of each of these parameters or the sum of weighted ratings. The weights assigned in the Bob Marshall were as follows: vegetation loss (2), mineral soil increase (3), tree damage (2), root exposure (3), development (1), cleanliness (1), social trails (2), camp area (4), and barren core camp area (2). Individual ratings are multiplied by these weights and then these products are summed to obtain the impact index. In the Bob Marshall this index could vary from 20 (least impact) to 60 (most impact). In figure 14b, the first column of values, under "calculation of impact index" is the weights; the second column consists of the ratings. Other weighting values have been used to reflect different opinions about the most critical types of impact. If you do not use weights, you are implicitly stating that each of these types of impact is equal in importance.

Appendix I: The Canyonlands Rapid Estimation Procedure (Adapted From Kitchell and Connor 1984)

This procedure is similar in many ways to the procedure used in the Bob Marshall; however, more information is collected and impact parameters have been adapted to desert environments. They also use slightly different forms to monitor sites used primarily by three different types of use: backpackers, river floaters, and people on four-wheel drive. Information on site characteristics is collected; the site is quickly mapped; photopoints are established; and an impact rating form is filled out.

The form (fig. 15) provides ratings for 24 parameters. The ratings include weights; some vary from 1.5 to 6, while others vary from 0.5 to 2. These ratings are summed. Then the condition of each site is considered to be excellent if this sum is between 25 and 37. It is considered good, fair, or poor if the sum is 38 to 62, 63 to 87, or 88 to 100, respectively.

Many of the ratings involve comparisons between the campsite and an adjacent undisturbed area, as described for the Bob Marshall procedure (appendix H). Most others should be self-explanatory from the form (fig. 15), although many definitions need to be agreed on by different field workers. For example, for tree and shrub damage, how much damage must occur for it to be counted?

1. VEGETATION COVER								
a. % cover	<10% reduction when compared with adjacent undisturbed area.	1.5	10-30% reduction.	3	30-60% reduction.	4.5	>60% reduction.	6
b. Composition	No exotic or disturbance species present.	1	10-20% of vegetation composed of exotics/disturbance species.	2	20-50% exotics and/or disturbance species.	3	>50% exotics and disturbance species.	4
c. Distribution	Vegetation evenly distributed throughout site.	0.5	Faint appearance of isolated "islands" of vegetation.	1	Up to 30% of vegetation built up around shrubs and "islands" of vegetation.	1.5	>30% of vegetation built up around shrubs and "islands" of vegetation.	2
2. SOIL DISTURBANCE								
a. Cryptogamic crust	No disturbance; still intact in appropriate habitat.	1	<30% reduction of crust when compared to adjacent/undisturbed area.	2	30-60% reduction of crust.	3	>60% reduction of crust.	4
b. Compaction/loosening/erosion	None apparent.	1	<30% of soil in site shows compaction (fine soils) or loosening (coarse soils).	2	30-60% of soil shows compaction or loosening; signs of erosion or gullying in 2 locations.	3	>60% of soil shows compaction or loosening; signs of erosion in 2 locations.	4
c. Excavations and trenches	None apparent.	1	1 or 2 small trenches or excavations.	2	2-4 excavations or trenches; a few may show slight erosion.	3	>4 excavations or trenches; some show erosion and gullying.	4
3. LITTER								
a. % cover	<10% disturbed.	1	10-35% reduction in contrast to adjacent/undisturbed areas	2	35-70% reduction compared to adjacent/undisturbed areas	3	>70% reduction compared to adjacent undisturbed areas.	4
b. Distribution	Evenly distributed.	1	50% of litter around edge of site and stable objects	2	50-80% around edge and stable objects.	3	>80% of litter around edges and stable objects.	4
c. Condition	No obvious signs of broken and crushed litter.	1	Slight appearance of crushed and broken litter.	2	<60% appears crushed or broken	3	>60% appears crushed or broken.	4
4. SIDE TRAILS								
a. Number	Only 1 present: not very obvious from main trail to or through site; no spur trails, and only a few isolated footprints present.	1	2 distinct trails from main trail to site or between attraction site (arch site or spring); no spurs; few isolated footprints.	2	3 distinct trails from main trail to site or between attraction site; 3 side trails or spurs developing; footprints apparent.	3	3 distinct trails from trail to site; 3 side or spur trails developing; trails have begun to merge; numerous footprints in and around trail and site.	4
b. Width	Average width <12".	1	Average width of 1 trail >12".	2	2 trails wider than 12".	3	>2 trails wider than 12"; trails merging.	4
c. Depth	Trail at same level as adjacent area.	1	1 trail-wearing below level of adjacent area.	2	At least 2 trails deeper than adjacent ground level.	3	All trails deeper than adjacent ground level.	4
5. SHRUB DAMAGE								
a. % damaged reduced vigor	None show any damage.	1.5	<10% of shrubs show damage (such as broken limbs, crushed appearance).	3	10-30% of shrubs show damage; 1 or 2 show reduced vigor as a result of damage.	4.5	>30% of shrubs show damage; 2 show reduced vigor; dead or dying shrubs present.	6
b. Root exposure	No roots exposed.	1.5	Exposed roots on 1 shrub.	3	Exposed roots on 2 shrubs.	4.5	Exposed roots on 3 shrubs.	6
6. TREE DAMAGE								
a. Broken limbs, gashes, damage	No damage; or no trees present.	1	<10% of trees have broken limbs, gashes, or other damage.	2	10-35% of trees have broken limbs, gashes, or other damage.	3	>35% of trees have broken limbs, gashes, or other damage.	4
b. Root exposure	No roots exposed; or no trees present.	1	1 root exposed in site.	2	2 roots exposed in site.	3	3 or more roots exposed in site.	4

Figure 15—The impact rating form used on backpacker campsites at Canyonlands National Park. For each parameter, circle the number to the right of the appropriate category and then sum all of these ratings.

7. **HUMAN WASTE**								
a. Toilet paper	None present.	1	1-2 pieces of toilet paper present.	2	3-4 pieces of toilet paper.	3	4 pieces of toilet paper.	4
b. Fecal matter	None present.	1	1 pile of feces encountered.	2	2 piles of feces.	3	>2 piles of feces encountered.	4
8. **FIREPITS**								
a. Number	None present.	1	Sign of 1 small firering (<2' diameter)	2	1 firering >2' diameter.	3	>1 firering.	4
b. Rock scarring	None.	1	<25% of rocks show fire scars.	2	26-50% of rocks show fire scars.	3	>50% show fire scars.	4
c. Charcoal and ash	None present.	1	Small trace of charcoal and ash concentrated in 1 pile; site can be easily returned to natural or undisturbed condition.	2	Concentrated pile of charcoal and ash in obvious pile.	3	Charcoal and ash scattered throughout site, mixing into soil.	4
9. **ROCK DISPLACEMENT**								
	None.	1	1-5 small rocks (6" diameter) moved; no tables or seats constructed.	2	>5 rocks moved; no tables or seats constructed	3	>5 rocks moved; tables, seats, and other items constructed.	4
10. **TRASH**								
	None present.	1	<4 pieces of trash, biodegradable or non-biodegradable.	2	4-6 pieces of trash.	3	>6 pieces of trash.	4
11. **PESTS AND INSECTS**								
	None.	1	1 small ant colony in or at edge of site.	2	1 ant colony; ants in <50% of site; few scattered signs of rodents within 20' of site.	3	>1 ant colony; ants throughout site; numerous signs of rodents: tracks, burrows, nests within 20' of site.	4

Excellent (E) = 25-37
Good (G) = 38-62
Fair (F) = 63-87
Poor (P) = 88-100

Figure 15 (Con.)

Appendix J: The Delaware Water Gap Rapid Estimation Procedure

This procedure was initially quite similar to the Bob Marshall procedure. With practice, it evolved into a procedure that collects only interval level data and is now most similar to the Eagle Cap method of measurements on permanent sampling units. Figure 16 shows the two pages of a completed field form. Impact parameters requiring explanation are as follows:

CAMPSITE INVENTORY AND IMPACT ASSESSMENT FIELD FORM

1)	Site Number:	3 1
2)	Site Name: 1=Calestini 2=Minisink 3=Namanock 4=Sandyston 5=Hornbeck 6=Shapnack 7=Buck Bar 8=Tom's Creek 9=Valley View 10=Peter's 11=Quinn 12=Decker's 13=Sambo 14=Freeman 15=Hamilton 16=Depew 17=Poxono 18=Hialeah 19=Schellenberger 20=Unnamed Site	2
3)	Site Designation: 1=designated 2=undesignated	1
4)	River Segment: 1=N-Milford 2=Milford-Dingmans 3=Ding.-Bushkill 4=Bush.-Smithfield 5=Smith.-S	2
5)	Site Location: 1=island 2=PA shore 3=NJ shore	1
6)	Substrate of Landing Area: 1=bedrock 2=cobble 3=sand 4=soil	3
7)	Length of Shoreline Disturbance (m):	1 9
8)	Distance to River (m):	1 3
9)	No. of Other Sites Visible from Campsite:	0
	*********** Do Campsite Map Before Proceeding ***********	
10)	No. of 8x10 ft. Tent Pads:	5
11)	Vegetative Ground Cover Onsite: 1=0-25% 2=26-50% 3=51-75% 4=76-95% 5=96-100%	1
12)	Vegetative Ground Cover Offsite: 1=0-25% 2=26-50% 3=51-75% 4=76-95% 5=96-100%	5
13)	Type of Ground Cover Onsite: 1=grass 2=herbaceous 3=ferns 4=moss	1
14)	Type of Ground Cover Offsite: 1=grass 2=herbaceous 3=ferns 4=moss	2
15)	Tree Canopy Cover Over Site: 1=0-25% 2=26-50% 3=51-75% 4=76-95% 5=96-100%	4
16)	No. of Trees Within and On Site Boundaries:	1 4
17)	No. of Trees With Moderate-Severe Damage:	4
18)	No. of Tree Stumps Within and On Site Boundaries:	1
19)	Total No. of Trails:	6
20)	Type of Fire Site: 1=stone 2=cement 3=steel 4=fire scar	1
21)	No. of Fire Sites:	2
22)	Toilet: 1=clivus 2=pit toilet 3=no toilet present	3

a

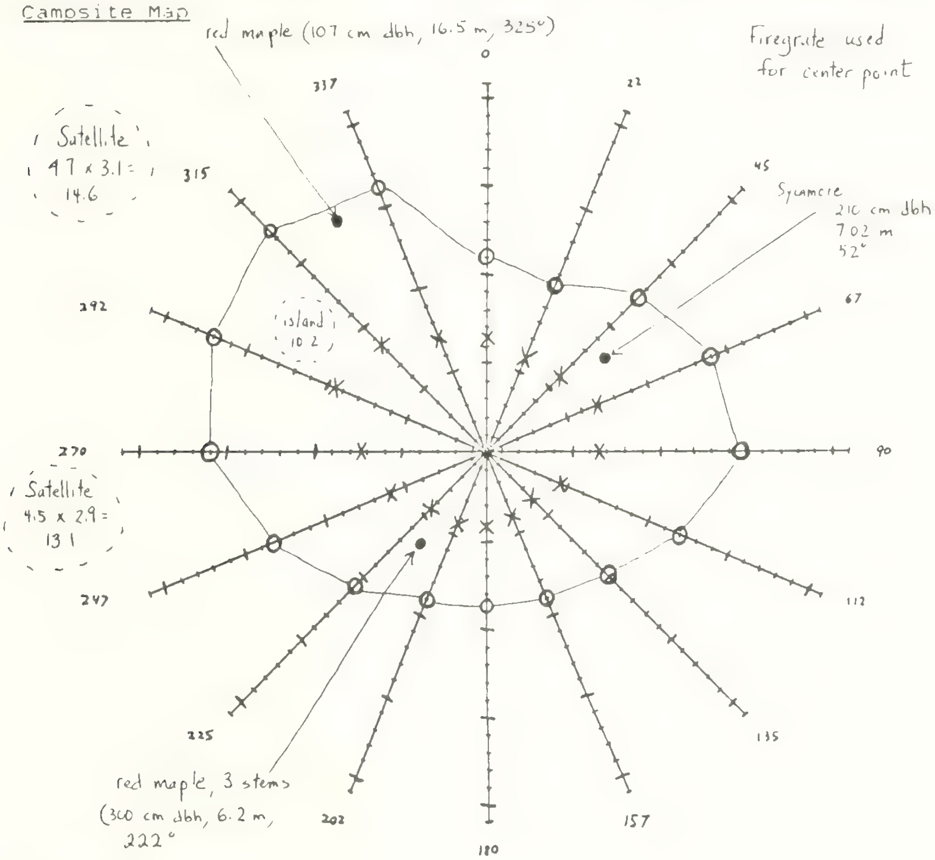
Figure 16—The front (a) and rear (b) sides of a completed form used to inventory campsites at Delaware Water Gap National Recreation Area.

23) No. of Garbage Bags of Litter Present: 0.2

24) No. of Human Waste Sites: 2

25) Date (Day/Mo/Yr): 7/19/88

Campsite Map



Compass Bearings:

	0	22	45	67	90	112	135	157	180	202	225	247	270	292	315	337
X:	6.2	6.0	6.0	6.9	6.5	4.8	3.9	4.0	4.0	4.2	4.5	6.0	7.3	8.5	8.6	7.0
O:	11.0	10.1	12.5	14.0	14.5	12.0	10.0	8.9	8.8	8.9	10.7	13.5	16.0	17.0	17.5	16.5

26) Devegetated (X) Area: _________ (sq.m.)

27) Campsite (O) Area (computed in DBASE) + Satellite Area 27.7 - Island Area 10.2 = _________ (sq.m.)

28) Coded By (Names): R. Benton and J Rituper

29) Comments: Access trail is very steep with significant tree root exposure

b

Figure 16 (Con.)

7. *Length of Shoreline Disturbance*: Distance (to the nearest meter) of shoreline where vegetation is absent or obviously disturbed by trampling. This judgment must be made by comparing the site to undisturbed shoreline. If the landing area is naturally barren (bedrock, for example), simply enter 1 m for the path width.

17. *Number of Trees With Moderate-Severe Damage*: A count of the number of trees (>1 inch [2.5 cm] d.b.h.) within or on campsite boundaries with large branches cut or broken off and/or large or extensive knife or ax scars. Include trees within undisturbed "islands" and disturbed "satellite" areas. Multiple tree stems that are joined at the base at or above ground level should be counted as one tree when assessing damage on any of its stems. If a multiple-stemmed tree has one of its stems cut, this would be assessed as tree damage, not as a stump. Do not count tree stumps as tree damage.

18. *Number of Tree Stumps*: A count of the total number of tree stumps (>1 inch [2.5 cm] diameter) within or on campsite boundaries. Due to the difficulty of differentiating stumps cut by humans from those created naturally, count all stumps regardless of origin.

23. *Number of Garbage Bags of Litter Present*: An estimate of amount of litter within the campsite and 100 ft (30 m) from the campsite boundaries, expressed as the number of 40-gallon garbage bags that could be filled with litter and tied at top. Use decimals to indicate fractions of a bag. Use zero if the site has only a handful of small items.

24. *Number of Human Waste Sites*: A count of the number of places with evident human waste and/or toilet paper, within 100 ft (30 m) of campsite boundaries.

26. *Devegetated Area*: Area (in square meters) of the devegetated central core of the campsite. Calculate in office, using procedures described in section on campsite map.

27. *Campsite Area*: Area (in square meters) of any ground showing clear evidence of human disturbance. For procedures, refer to the following section.

Campsite Map: Draw a map of the campsite by connecting points on campsite boundaries along 16 transects radiating from a center point. Begin by locating a center point and referencing it to three permanent features, usually trees. Standing at the center point, consecutively establish 16 transects, radiating from the center point, along the following bearings (not corrected for declination): 0, 22, 45, 67, 90, 112, 135, 157, 180, 202, 225, 247, 270, 292, 315, and 337 degrees. Measure the distance along each transect to the first significant amount of vegetation, defined as the first location where a 0.3- by 0.3-ft (1- by 1-m) quadrat centered on the transect line would have more than 25 percent vegetative cover. Measure from the center point to the closest edge of this imaginary quadrat and record this distance for the appropriate bearing in the row labeled "X." Also place an "X" on the map at the measured distance (map intervals are equal to 1 m each). These will define the devegetated area, which will be calculated in the office, using basic trigonometry. At the same time, measure the distance along each transect to the campsite boundary, indicated by a pronounced change in vegetation cover, height or composition, or in surface litter. Note this distance in the row labeled "O" and place an "O" on the map. These will define the main campsite area, which will be calculated in the office using basic trigonometry. Finally, estimate the area of untrampled "islands" of vegetation within campsite boundaries (to be subtracted from the total campsite area) and the area of any disturbed "satellite" areas outside campsite boundaries (to be added to the total campsite area). The size of these areas can be estimated by superimposing an appropriate geometric figure over the area and taking the requisite linear measurements.

Appendix K: The Hardware and Software Used to Collect Data at Yosemite (Source: Sydoriak in press)

Hardware—The HP71B microcomputer weighs only 12 oz (340 g) and runs on four AAA batteries. With addition of an HP82162A thermal printer for hard copies, and the HP82401A HP-IL interface, which facilitates communication between the two, the package weighs less than 3 lb (1.4 kg). The computer is small—1 inch (2.5 cm) by 4 inches (10 cm) by 8 inches (20 cm)—making it very easy to transport.

The HP71B comes with only 16K RAM (random access memory). The risk of memory loss is significant in the unadorned HP71B. Therefore, two 64K RAM memory modules from Firmware, Inc., complete with their own battery backup, were added. These retain their memory even when removed from the computer. When one becomes full, the second can be installed in seconds. Programs and data are stored in the module in case of memory loss.

An HP82161A digital cassette drive is used to download data from the memory module to tape at the end of each collection period. It protects data and program files from accidental memory loss.

The cassettes are unloaded to an IBM-compatible personal computer via an HP821643A RS-232-C interface. Programs on the personal computer check the data for errors not detectable in the field and prepare the data for analyses.

Although watertight cases are available, the cost and weight are excessive. Heavy-duty Ziploc bags, though not waterproof due to the need to run cables to the printer, keep dust and rain out, and permit keypunching. The computer and printer are worn around the waist in a customized carrying pouch. This arrangement leaves the hands free for keypunching.

Software—The HP71B computer has a powerful set of BASIC functions. Customized data collection programs were developed to be as automatic as possible so that untrained individuals could learn to work with them easily. As an added protection, a data entry and troubleshooting guide is carried with the HP71B.

On power-up, a menu appears for the three main procedures: trails data input, campsite data input, or storage to cassette. After the operator indicates the desired program, it is automatically loaded. The most recent data are displayed to aid in determining where the operator left off.

As each data field is entered, the program advances to the next required field. Cursor keys allow access to any field in the current campsite or trail segment data group. Unfortunately, due to the absence of an editor (takes up too much memory), previous data groups are not accessible, and corrections must be recorded on paper and reentered on the office personal computer.

Each data item is checked for errors upon entry. Battery power is checked after each entry. When a low battery is detected, the anunciator signal is activated and the machine locks up until new batteries are installed. According to Hewlett-Packard, a low-battery signal still allows up to 15 minutes of program time. The use of a low-power state command, as in the programs, extends battery time.

When a new campsite is encountered, the previous data are stored as text in a sequential file and variables are cleared for the new data set. Other options suspend program operation indefinitely to permit battery replacement or to interrupt the camp program to run the trails program. Total program, lex file, and associated file bytes needed for the inventory program are about 15K. Data are stored in the 64K memory module. Only 32K at a time are accessible to a file, so checks have to be made frequently to determine when a 32K file partition is becoming filled. Firmware, Inc., states that this limitation may soon be overcome.

Cole, David N. 1989. Wilderness campsite monitoring methods: a sourcebook. Gen. Tech. Rep. INT-259. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 57 p.

Summarizes information on techniques available for monitoring the condition of campsites, particularly those in wilderness. A variety of techniques are described and evaluated; sources of information are also listed. Problems with existing monitoring systems and places where refinement of technique is required are highlighted.

KEYWORDS: wilderness management, campsite management, camping impacts, campsite condition, wildland ecology

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Forest Service

**Intermountain
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BEHAVE: Fire Behavior Prediction and Fuel Modeling System — BURN Subsystem, Part 2

Patricia L. Andrews
Carolyn H. Chase

THE AUTHORS

PATRICIA L. ANDREWS is a mathematician stationed at the Intermountain Fire Sciences Laboratory in Missoula, MT. She received her B.A. in mathematics and chemistry from Eastern Montana College, Billings, in 1970, and her M.A. in mathematics and computer sciences in 1973 from the University of Montana, Missoula. She has been a member of the fire behavior research work unit since 1973. She is now team leader of the systems development and application team.

CAROLYN H. CHASE is a mathematician stationed at the Intermountain Fire Sciences Laboratory in Missoula, MT. She received her B.A. in mathematics from the University of Montana, Missoula, in 1969. Following 2 years of graduate study in mathematics at the University of Montana, she worked for 2 summers for Northern Region Fire and Aviation Management. In 1978, she began work at the Intermountain Fire Sciences Laboratory and is a member of the fire behavior research work unit.

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Intermountain Research Station
324 25th Street
Ogden, UT 84401

BEHAVE: Fire Behavior Prediction and Fuel Modeling System—BURN Subsystem, Part 2

Patricia L. Andrews
Carolyn H. Chase

INTRODUCTION

The BEHAVE fire behavior prediction and fuel modeling system is a set of interactive computer programs. BEHAVE provides mathematical prediction models in one easy-to-use package. This paper describes prediction capabilities that have been added to the system.

Since 1984, BEHAVE has been used by land managers for a variety of fire management needs. A user can tailor predictions to specific needs based on the resolution of the input and interpretation of the output. For example, windspeed might be measured on site for real-time prediction of wildfire behavior. On the other hand, windspeed can be assigned a range of values in order to make assessments for planning purposes. Example uses of BEHAVE predictions are determining appropriate suppression action, predicting the growth of a wilderness fire, prescribed fire planning, setting dispatch levels, and after-the-fact predictions for an investigation.

This paper is the third in a series of papers that describe the BEHAVE system. Burgan and Rothermel (1984) described the FUEL subsystem of BEHAVE, used for designing custom fuel models. Andrews (1986) described the initial BURN subsystem, the operational fire behavior prediction part of BEHAVE. This paper covers additions that have been made to the BURN subsystem.

Part 1 of the BURN manual described the FIRE1 program. This paper is Part 2 of the BURN manual and describes additions to the FIRE1 program and the new FIRE2 program. The information in Part 1 is still valid. Worksheets for all modules in the FIRE1 and FIRE2 programs are in this manual (appendix B).

We assume that you are familiar with BEHAVE, specifically with the material in Part 1 of the BURN manual. References will be made to that paper (Andrews 1986) by page number (for example, Part 1, p. 23). As with Part 1, the emphasis of this paper is on description of the prediction models. You are responsible for supplying valid input and for properly interpreting output.

OVERVIEW OF THE BEHAVE SYSTEM

A diagram of the BEHAVE system design is shown in figure 1. The BURN subsystem previously consisted of only one program. It now has two, FIRE1 and FIRE2. The only reason for the split is to limit program size.

BEHAVE's "user-friendly" design makes it unnecessary to provide detailed instructions on how to run the programs. Annotated runs of the FIRE1 and FIRE2 programs are given in appendix A. Operation of all of the BEHAVE programs is based on keywords. A list of all keywords in the BURN subsystem and a brief description of each is shown in figure 2. Module keywords (DIRECT, SITE, SIZE, ...) are used to specify the prediction that is desired. Operation keywords (INPUT, LIST, CHANGE, RUN) are used to enter input and obtain output. Mode keywords (WORDY, TERSE, PAUSE, ...) are used to set a switch that remains in effect until you change it. Rescue keywords (KEY, HELP) should rescue you if you get mixed up.

All of the modules can be used independently. Some of them can also be linked to others as shown in figure 3. In that case, input and/or output is carried over from one module to the next.

Input/output sheets for all modules of the BURN subsystem are included in appendix B. In some cases, they are different from those given in Part 1. To avoid confusion, the date is at the bottom of each worksheet.

The Input/Output sheets give line numbers, item names, both English and metric units, comments, and one blank. These are information sheets and not worksheets. Most users will use computer printout to document runs rather than completing a worksheet. Custom worksheets can be designed as needed.

BEHAVE System Design

SYSTEM — **SUBSYSTEMS** — **PROGRAMS** — **MODULES**

- **BEHAVE**
  FIRE BEHAVIOR PREDICTION AND FUEL MODELING SYSTEM
  - **FUEL**
    FUEL MODELING SUBSYSTEM
    - **NEWMDL**
      INITIAL FUEL MODEL DEVELOPMENT PROGRAM
    - **TSTMDL**
      FUEL MODEL TEST AND ADJUSTMENT PROGRAM
  - **BURN**
    FIRE BEHAVIOR PREDICTION SUBSYSTEM
    - **FIRE 1**
      FIRE BEHAVIOR PREDICTION PROGRAM
      - **DIRECT**
        SPREAD RATE, FLAME LENGTH, AND INTENSITY
        (DIRECT INPUT OF GENERAL INPUT)
      - **SITE**
        SPREAD RATE, FLAME LENGTH, AND INTENSITY
        (SITE-SPECIFIC INPUT)
      - **SIZE**
        AREA AND PERIMETER
      - **CONTAIN**
        ATTACK FORCE REQUIREMENTS
      - **DISPATCH**
        AUTOMATIC LINKING OF DIRECT, SIZE, AND CONTAIN
      - **SPOT**
        MAXIMUM SPOTTING DISTANCE
      - **SCORCH**
        CROWN SCORCH HEIGHT
      - **MORTALITY**
        TREE MORTALITY LEVEL
      - **MAP**
        MAP DISTANCES
      - **SLOPE**
        SLOPE FROM TOPOGRAPHIC MAPS
    - **FIRE 2**
      FIRE BEHAVIOR PREDICTION PROGRAM
      - **MOISTURE**
        FINE DEAD FUEL MOISTURE, TABLE AND GRAPHIC OPTIONS
      - **IGNITE**
        PROBABILITY OF IGNITION
      - **RH**
        RELATIVE HUMIDITY FROM WET BULB AND DRY BULB TEMPERATURES

Figure 1—Subsystems, programs, and modules of the BEHAVE system.

FIRE1 only

Module Keywords

DIRECT	Accepts direct input of the basic values to calculate spread rate, flame length, and intensity.
SITE	Accepts site-specific input to calculate spread rate, flame length, and intensity. Fine dead fuel moisture is an intermediate value.
SIZE	Calculates area and perimeter of a point source fire.
CONTAIN	Calculates either line construction capabilities needed or final fire size.
DISPATCH	Automatically links DIRECT, SIZE, and CONTAIN
SPOT	Calculates maximum spotting distance from torching trees, a burning pile, or wind-driven surface fire.
SCORCH	Calculates crown scorch height
MORTALITY	Calculates level of tree mortality
MAP	Translates calculated distances to map distances
SLOPE	Calculates slope from topographic map measurements
CUSTOM	Specifies a custom fuel model file to be used or lists what is in a fuel model file

FIRE2 only

Module Keywords

MOISTURE	Calculates fine dead fuel moisture
IGNITE	Calculates probability of ignition
RH	Calculates relative humidity from wet bulb and dry bulb temperatures

FIRE1 and FIRE2

Operation Keywords

INPUT	Asks for all input of the current module
LIST	Lists current input values
CHANGE	Changes individual input values by line number
RUN	Does calculations and presents results

Mode Keywords

WORDY	Gives extra messages and explanations throughout the run (default)
TERSE	Skips extra messages and explanations
PAUSE	Limits display to at most 24 lines at a time for a video display terminal (default)
NOPAUSE	No pause in display for a terminal with hard-copy output
LOG	Writes results of LIST, RUN and COMMENT to a file to be printed at a later time
NOLOG	turns off the LOG option (default)
ENGLISH	English units (default)
METRIC	Metric units
PERCENT	Slope in percent (default)
DEGREES	Slope in degrees

Rescue Keywords

KEY	Prints the keywords that are allowed at the current point along with a brief description of each
HELP	Tells you where you are in the program and what you can do next

Other Keywords

QUIT	Gets back to the previous level in the keyword hierarchy or terminates the run
COMMENT	Allows the user to annotate a run in a log file
STATUS	Gives the status of the mode keywords and the names of the fuel model file and the log file

Figure 2—Keyword summary for the BURN subsystem (FIRE1 and FIRE2 programs).

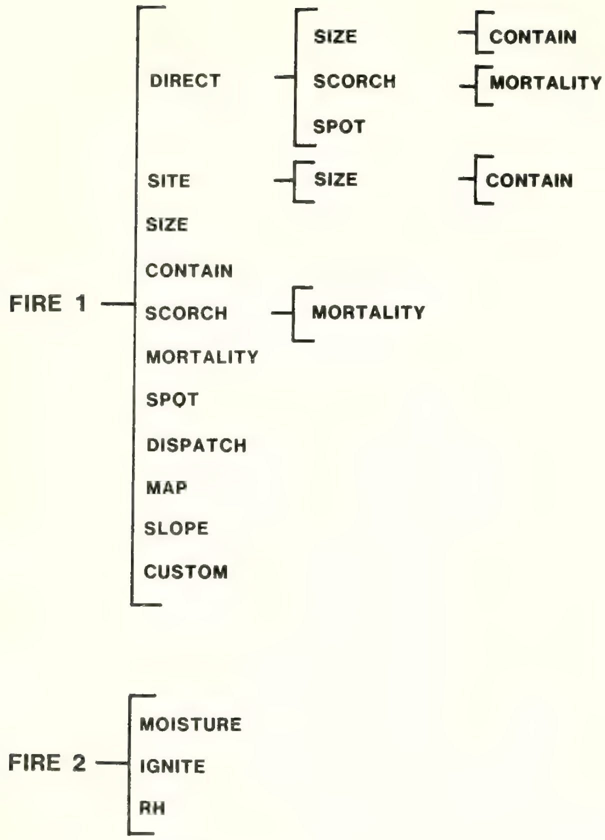


Figure 3—Keyword hierarchy for the BURN subsystem (FIRE1 and FIRE2 programs).

SUMMARY OF ADDITIONS AND CHANGES

The following is a summary of the capabilities that have been added to BEHAVE. They are listed according to keyword. The remainder of this paper describes these items in detail.

LOG/NOLOG - When the LOG mode is set, the results of LIST, RUN, COMMENT, and CUSTOM are written to a file. When the NOLOG mode is set, nothing is written to the file.

COMMENT - The user is allowed to enter a description of the run.

ENGLISH/METRIC - The option of either English or metric units can be set.

PERCENT/DEGREES - The option of specifying slope as either percentage or degrees can be set.

STATUS - The status is given for the mode keywords and, if they are in use, the names of the fuel model file and the log file.

SCORCH - Crown scorch height can be calculated.

MORTALITY - Level of tree mortality can be calculated.

SPOT - The wind-driven surface fire option has been added. Several southern tree species have been added to the torching tree option.

MAP - Calculated distances can be translated to map measurements.

SLOPE - Slope can be calculated from topographic map measurements.

IGNITE - Probability of ignition can be calculated.

MOISTURE - Table and graphic options are available for the fine dead (1-hour) fuel moisture model that is also in SITE.

RH - Relative humidity can be calculated from wet bulb and dry bulb temperatures.

UTILITY KEYWORDS (LOG, NOLOG, COMMENT, ENGLISH, METRIC, PERCENT, DEGREES, STATUS)

Several new utility keywords are available in the FIRE1 and FIRE2 programs: LOG, NOLOG, COMMENT, ENGLISH, METRIC, PERCENT, DEGREES, and STATUS. Use of these keywords is illustrated in appendix A.

Saving Results in a File for Printing (LOG and NOLOG)

BEHAVE involves a lot of interaction between you and the computer. Although it is most convenient to access BEHAVE through a video display terminal, there is often a need to save results on paper. The input and output are needed, but not all of the questions and answers.

LOG and NOLOG are mode keywords. When the LOG mode is set, the results of LIST, RUN, COMMENT, and CUSTOM are saved in a file that can later be printed. You can turn the option on and off at any time by typing LOG or NOLOG. You should get in the habit of always typing LIST before RUN. Predictions are meaningful only if they are associated with their input values.

When you first type the keyword LOG, you are asked to specify a file name. When you are finished running the program, you will be reminded that you have logged some information to a file and that you should print that file immediately and then delete it. It is important that you follow this advice to avoid wasting disk space on unneeded files.

Programs are written in standard Fortran so that they can easily be transported to a variety of computers. File handling, however, is not standard among computers. Naming of files, as well as procedures for printing and deleting them, depends on the computer being used, not on the BEHAVE system.

Adding User Comments to Output (COMMENT)

The keyword COMMENT allows you to document your logged runs. After you enter the keyword COMMENT, you may type in as many lines of description as you wish. Up to 80 characters may be typed per line; each line must be followed by a return. Two asterisks typed on a line by themselves, followed by a return, indicate that you are finished with your comment.

Changing Units (ENGLISH, METRIC, PERCENT, and DEGREES)

The previous version of BEHAVE used only English units of measurement. You now have a choice of either English or metric. The units mode can be changed at any time by typing the keywords ENGLISH or METRIC. The default is ENGLISH. It is possible, for example, to enter input in English units, enter the keyword METRIC, and then obtain the output in metric units. An example of this is given in appendix A.

Both English and metric units are given on the input/output sheets in appendix B. We have used the metric units that are acceptable to many fire specialists. Those who wish to permanently change the units used in their program may contact the authors. We will tell you where to change the source code.

You can specify slope steepness in either percentage or degrees whether you are using English or metric units. The mode can be changed at any time, using the keywords PERCENT or DEGREES. The default is PERCENT.

Checking the Status of Files and of Mode Keywords (STATUS)

The keyword STATUS allows you to check the status of the mode keywords and to see the names of the fuel model file and the log file that you are using. An example is shown in figure 4. Other examples are given in appendix A.

```
**** FIRE1 STATUS REQUEST ****

    PROMPT MODE    : WORDY
    DISPLAY MODE   : PAUSE
    LOG FILE NAME  : LOGFILE
    LOG FUNCTION   : ON
    FUEL FILE NAME: UNDECLARED
    DISPLAY UNITS  : ENGLISH
    SLOPE UNITS    : PERCENT
```

Figure 4—Use of the keyword STATUS gives the current status of each of the mode keywords.

CROWN SCORCH HEIGHT (SCORCH)

The SCORCH module of the FIRE1 program predicts lethal crown scorch height from flame length, ambient temperature, and midflame windspeed. As can be seen in figure 3, SCORCH can be used as either an independent module or it can be linked to DIRECT. Predictions from SCORCH can also be carried over to the MORTALITY module, as described in the next section.

The model developed by Van Wagner (1973) estimates the maximum height in the convection column at which the lethal temperature for live crown foliage is reached. This temperature is assumed to be 140 °F (60 °C). The scorch height model is based on the relationship of fireline intensity to temperature above the fire and on the shape of the convection column as it is affected by light winds. Flame length is used as a measure of the intensity of the heat source. The model is based on 13 test fires: eight in a stand of red pine and white pine, two in jack pine, one in red oak, and two in a red pine plantation.

Figure 5 shows the results of using SCORCH as an independent module. In this case a range of flame lengths and midflame windspeeds are examined. Notice that for a fixed flame length of 4 feet, as windspeed increases, scorch height decreases. This is caused by the flattening effect of wind as illustrated in figure 6. Although two fires may each have flame lengths of 4 feet, scorch heights will differ if the windspeeds are different.

Figure 7 shows the results of SCORCH being linked to DIRECT. On a single fire, when the windspeed increases, the flame length also increases. This effect can be seen in figure 7A where flame length is calculated for a range of windspeeds. If flame length remains constant with increasing windspeed (as in figure 5), then it must have been balanced by a change in another variable, such as increasing fuel moisture. Notice that, for this example, three combinations of 1-hour fuel moisture and windspeed result in 4-foot flame lengths. The resulting scorch height predictions are circled in figure 7B. Notice where those three values appear on the table in figure 5.

When SCORCH is used independently, flame length is an input value. When SCORCH is linked to DIRECT (fig. 3), flame length is calculated. SCORCH can be linked to DIRECT when the steady-state assumptions (Part 1, p. 9) are appropriate. SCORCH can be used independently when the flame length is controlled by the pattern of ignition.

Effective windspeed is used in the calculation of flame length in DIRECT (Part 1, p. 16). Midflame windspeed is used in the scorch height calculation in SCORCH. The DIRECT run in figure 8A illustrates that the effective windspeed for flanking and backing fires (spread directions 90 and 180 degrees) is much less than for the head fire (spread direction 0 degrees). Midflame windspeed and calculated flame lengths in figure 8B are carried over for the scorch height calculations shown in figure 8C. For the head fire, the increasing flame lengths easily offset the flattening effect of wind, and scorch height increases. But the low flame lengths for the flanking and backing fires are tilted enough by the midflame wind that the scorch height decreases.

```
SCORCH
 1--AMBIENT AIR TEMP, F          75.0
 2--FLAME LENGTH, FT              1.0    2.0    3.0    4.0    5.0    6.0    7.0
 3--MIDFLAME WINDSPEED, MI/H       .0    1.0    2.0    3.0    4.0    5.0    6.0
```

CROWN SCORCH HEIGHT, FT (V4.0)

FLAME LENGTH (FT)	MIDFLAME WINDSPEED, MI/H 0.	1.	2.	3.	4.	5.	6.
1.	3.	3.	2.	1.	1.	1.	0.
2.	8.	8.	7.	6.	5.	3.	3.
3.	15.	15.	14.	13.	11.	9.	7.
4.	23.	23.	22.	21.	18.	16.	14.
5.	32.	32.	31.	30.	27.	25.	22.
6.	41.	41.	41.	40.	37.	34.	31.
7.	52.	52.	51.	50.	48.	45.	42.

Figure 5—Example independent SCORCH run. Note that for a fixed flame length, as windspeed increases, crown scorch height decreases.

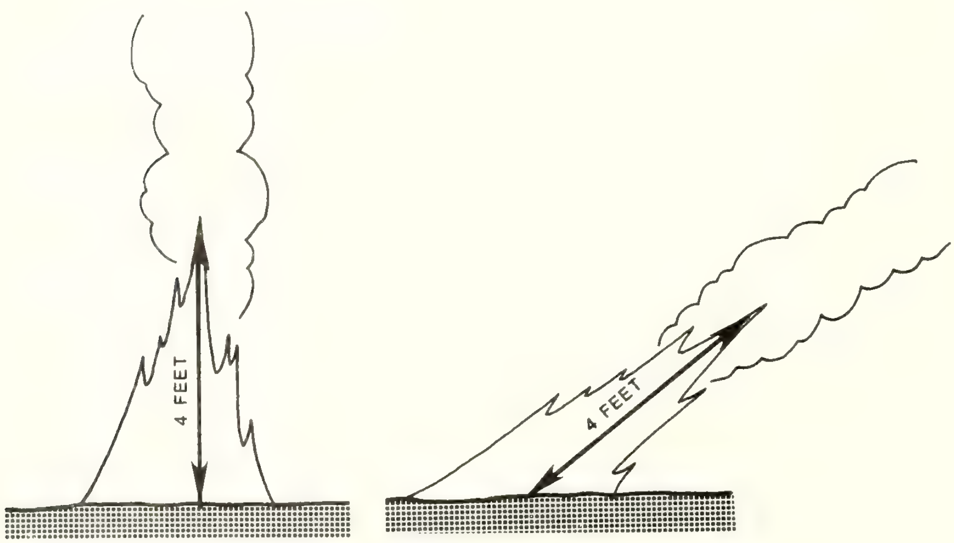


Figure 6—A 4-foot flame with no wind results in higher crown scorch height than a 4-foot flame which is flattened by the wind.

```
DIRECT
 1--FUEL MODEL                     2 -- TIMBER (GRASS AND UNDERSTORY)
 2--1-HR FUEL MOISTURE, %        4.0   6.0   8.0  10.0  12.0
 3--10-HR FUEL MOISTURE, %       6.0
 4--100-HR FUEL MOISTURE, %      6.0
 5--LIVE HERBACEOUS MOIS, %    200.0
 7--MIDFLAME WINDSPEED, MI/H      .0   1.0   2.0   3.0   4.0   5.0   6.0
 8--TERRAIN SLOPE, %              .0
 9--DIRECTION OF WIND VECTOR      .0
10--DIRECTION OF SPREAD           .0  (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM THE WIND VECTOR
```

A FLAME LENGTH, FT (V4.0)

1-HR MOIS (%)	MIDFLAME WIND, MI/H 0.	1.	2.	3.	4.	5.	6.
4.	1.7	2.2	3.0	4.0	5.0	5.9	6.8
6.	1.5	2.0	2.8	3.7	4.5	5.4	6.2
8.	1.4	1.9	2.7	3.5	4.3	5.1	5.9
10.	1.3	1.7	2.5	3.2	4.0	4.7	5.5
12.	1.1	1.4	2.0	2.7	3.3	4.0	4.6

```
SCORCH-LINKED-TO-DIRECT
 1--AMBIENT AIR TEMP, F         75.0
 2--FLAME LENGTH, FT            OUTPUT FROM DIRECT. RANGE =    1.1 TO    6.8
 3--MIDFLAME WINDSPEED, MI/H    SAVED FROM DIRECT.  RANGE =     .0 TO    6.0
```

B CROWN SCORCH HEIGHT, FT (V4.0)

1-HR MOIS (%)	MIDFLAME WIND, MI/H 0.	1.	2.	3.	4.	5.	6.
4.	6.	9.	15.	21.	27.	33.	39.
6.	6.	8.	13.	18.	23.	28.	34.
8.	5.	8.	12.	16.	21.	26.	30.
10.	5.	7.	10.	14.	18.	22.	26.
12.	4.	5.	8.	10.	13.	16.	18.

Figure 7—SCORCH linked to DIRECT. Three combinations of 1-hour moisture and windspeed give predicted flame lengths of 4 feet as indicated in 7A. The corresponding scorch height predictions are given in 7B.

```
DIRECT
 1--FUEL MODEL                        7 -- SOUTHERN ROUGH
 2--1-HR FUEL MOISTURE, %         10.0
 3--10-HR FUEL MOISTURE, %        10.0
 4--100-HR FUEL MOISTURE, %       10.0
 6--LIVE WOODY MOISTURE, %       150.0
 7--MIDFLAME WINDSPEED, MI/H        .0   2.0   4.0   6.0
 8--TERRAIN SLOPE, %                .0
 9--DIRECTION OF WIND VECTOR        .0
10--DIRECTION OF SPREAD             .0  90.0 180.0
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM THE WIND VECTOR
```

A

```
==================================================================
EFFECTIVE WINDSPEED, MI/H                                   (V4.0)
==================================================================
MIDFLAME I        SPREAD DIRECTION, DEG
  WIND   I
         I     0.     90.    180.
 (MI/H)  I--------------------------------------------------------
         I
  0.     I     .0      .0      .0
         I
  2.     I    2.0      .4      .0
         I
  4.     I    4.0      .6      .1
         I
  6.     I    6.0      .6      .1
```

B

```
==================================================================
FLAME LENGTH, FT                                            (V4.0)
==================================================================
MIDFLAME I        SPREAD DIRECTION, DEG
  WIND   I
         I     0.     90.    180.
 (MI/H)  I--------------------------------------------------------
         I
  0.     I    1.2     1.2     1.2
         I
  2.     I    2.8     1.5     1.2
         I
  4.     I    4.1     1.6     1.2
         I
  6.     I    5.3     1.7     1.2
```

```
SCORCH-LINKED-TO-DIRECT
 1--AMBIENT AIR TEMP, F          80.0
 2--FLAME LENGTH, FT             OUTPUT FROM DIRECT. RANGE =    1.2 TO     5.3
 3--MIDFLAME WINDSPEED, MI/H     SAVED FROM DIRECT.  RANGE =     .0 TO     6.0
```

C

```
==================================================================
CROWN SCORCH HEIGHT, FT                                     (V4.0)
==================================================================
MIDFLAME   I        SPREAD DIRECTION, DEG
  WIND     I
           I     0.     90.    180.
 (MI/H)    I------------------------------------------------------
           I
  0.       I     4.      4.      4.
           I
  2.       I    14.      5.      3.
           I
  4.       I    21.      3.      2.
           I
  6.       I    26.      2.      1.
```

Figure 8—SCORCH linked to DIRECT. SCORCH uses midflame windspeed rather than effective windspeed.

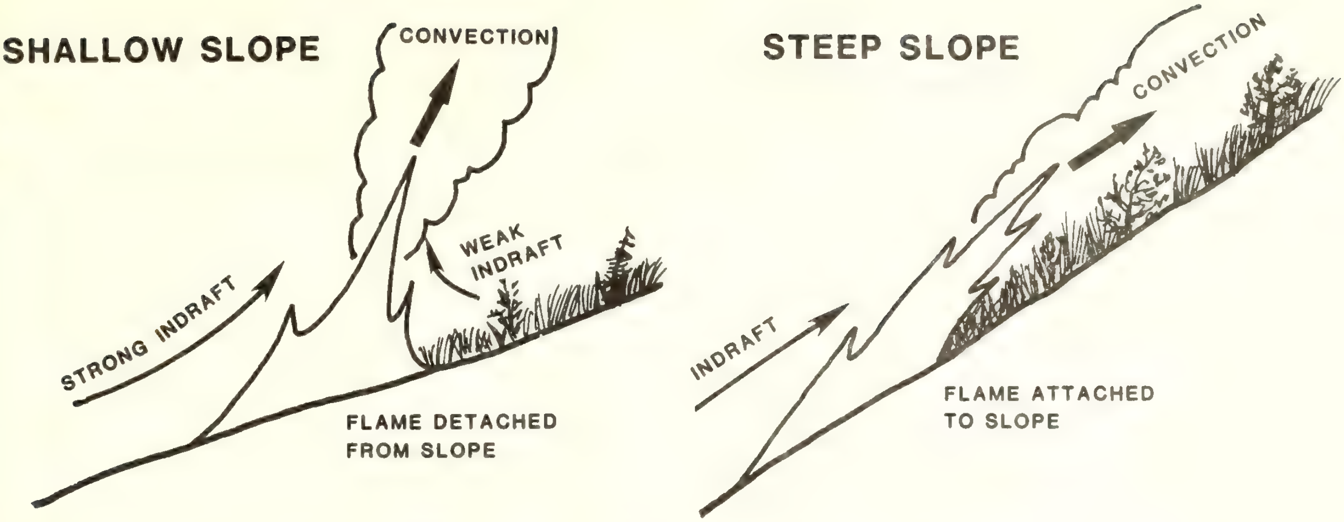


Figure 9—Flame detached from a shallow slope and flames attached to a steep slope.

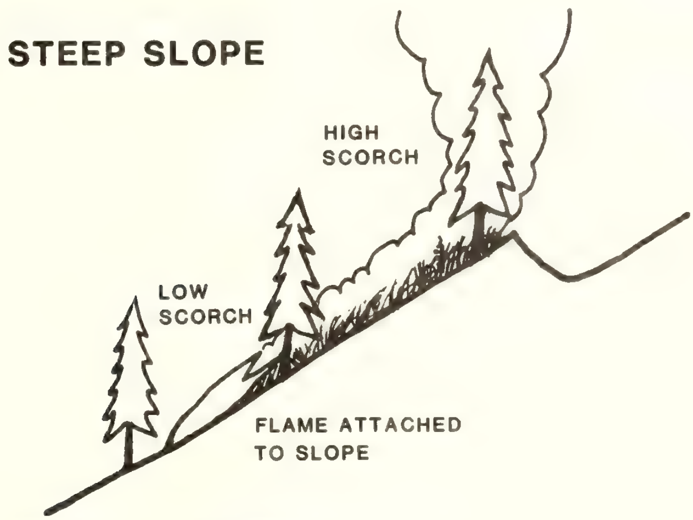


Figure 10—Scorching conditions on a steep slope.

The scorch height model was developed for flat ground. It should be used on slopes only with care. As pointed out in the previous example, the scorch height calculations use midflame windspeed, not effective windspeed. If SCORCH is used when percentage of slope is greater than zero, the slope is essentially ignored except in the effect that it has on the flame length calculations in DIRECT. SCORCH uses midflame windspeed as if the fire were on flat ground.

When using scorch height predictions in mountainous terrain, one must realize that the flame may or may not attach itself to the slope. When it does attach, the hot convective gases and smoke flow up the slope close to the surface rather than rising vertically as shown in figure 9. As stated by Rothermel (1985): "If an overstory of trees is present, the scorch height of trees on a steep slope will be affected. Attachment of the flame to the slope will reduce the scorch height in trees above the flames from what would be expected on level ground where the flames stand vertically. But further up the slope at a ridge line where the convection column breaks from the surface and rises, the concentration of hot gases will scorch higher than expected on the flat." (See fig. 10.) Rothermel further points out that there is no definitive research on the problem of flame attachment. It appears from both lab work and discussions with users that the flame becomes attached near 50 percent slope when there is no prevailing wind.

Care should be taken in applying the scorch height predictions outside of the range of conditions for the 13 test fires used in developing the model. Fireline intensities for those fires were from 19 to 363 Btu/ft/s, which according to the equations used in BEHAVE, convert to flame lengths of 1.8 to 6.8 feet. The scorch heights were

from 6.5 to 56 feet. Temperatures were 73 to 88 °F and midflame windspeeds were 1.5 to 3 mi/h. According to Van Wagner (1973): "Since scorch height for the present set of fires is so well correlated with fire intensity alone, there is not much room for improvement by adding the effects of air temperature and wind . . . . If air temperature or wind differ markedly from average, then their additional effects may be tentatively estimated from the theory presented."

Other limitations of SCORCH are related to the model that is used to calculate flame length in DIRECT. In developing the crown scorch model, Van Wagner calculated fireline intensity from measurements of rate of spread and of fuel weight before and after burning. In BEHAVE, we use calculated flame length and fireline intensity as described on p. 10-11 of Part 1. This calculation is weighted to the fine fuels and does not include larger fuels that burn after the flaming front has passed. An alternative to using calculated flame length is to use SCORCH independent of DIRECT and enter flame length directly.

The models in DIRECT also assume that fuels are uniform and continuous. SCORCH then gives average values over an area, although variation within a single fire may be considerable.

As with all mathematical models that are used for fire behavior prediction, the scorch height model has limitiations. Even though fire managers are aware of those limitations, they use it frequently in prescribed fire planning. SCORCH was added to BEHAVE because of overwhelming user request. The appeal is that it is a simple model with few inputs. It gives a quantitative link between fire behavior and fire effects.

TREE MORTALITY LEVEL (MORTALITY)

The MORTALITY module of the FIRE1 program predicts percentage of tree mortality from scorch height, tree height, crown ratio, and bark thickness (which can be determined from tree species and tree diameter). It can be used in designing fire prescriptions that achieve acceptable tree survival. As shown in figure 3, MORTALITY can be used as an independent module. It can also be linked to SCORCH, which in turn can either be used independently or linked to DIRECT as described in the previous section.

The model was developed by Ryan and Reinhardt (1988). Formulation for managers including a nomogram and discussion of applications is given in Reinhardt and Ryan (1988). The model is based on tree mortality data taken on 43 prescribed fires in four Western States. This included 2,356 individual trees and seven western conifer species. Mortality was monitored for at least 2 years following the fire.

The model is based on the assumption that trees of different species are similar in their response to a given level of injury and that the level of damage depends on the fire and on tree characteristics (bark thickness, tree height, crown ratio). The basic model in MORTALITY calculates percentage of mortality from bark thickness and percentage of crown volume scorched. In order to make the model more useful as a predictive tool, bark thickness can be either entered directly or determined by tree diameter and species, and percentage of crown volume scorched is calculated from scorch height, tree height, and crown ratio. The relationship among the input values, intermediate values, and percentage of mortality is shown in figure 11. An illustration of several crown ratio values is shown in figure 12.

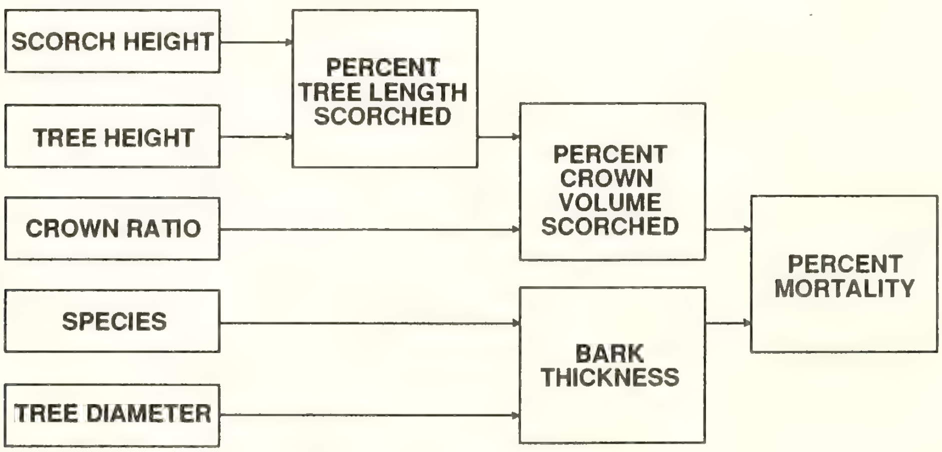


Figure 11—MORTALITY module user input, intermediate values, and final result.

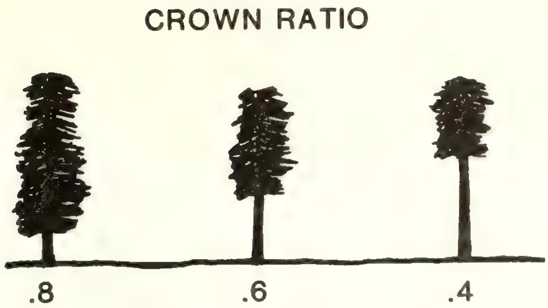


Figure 12—Illustration of three crown ratio values. Crown ratio is an input to MORTALITY.

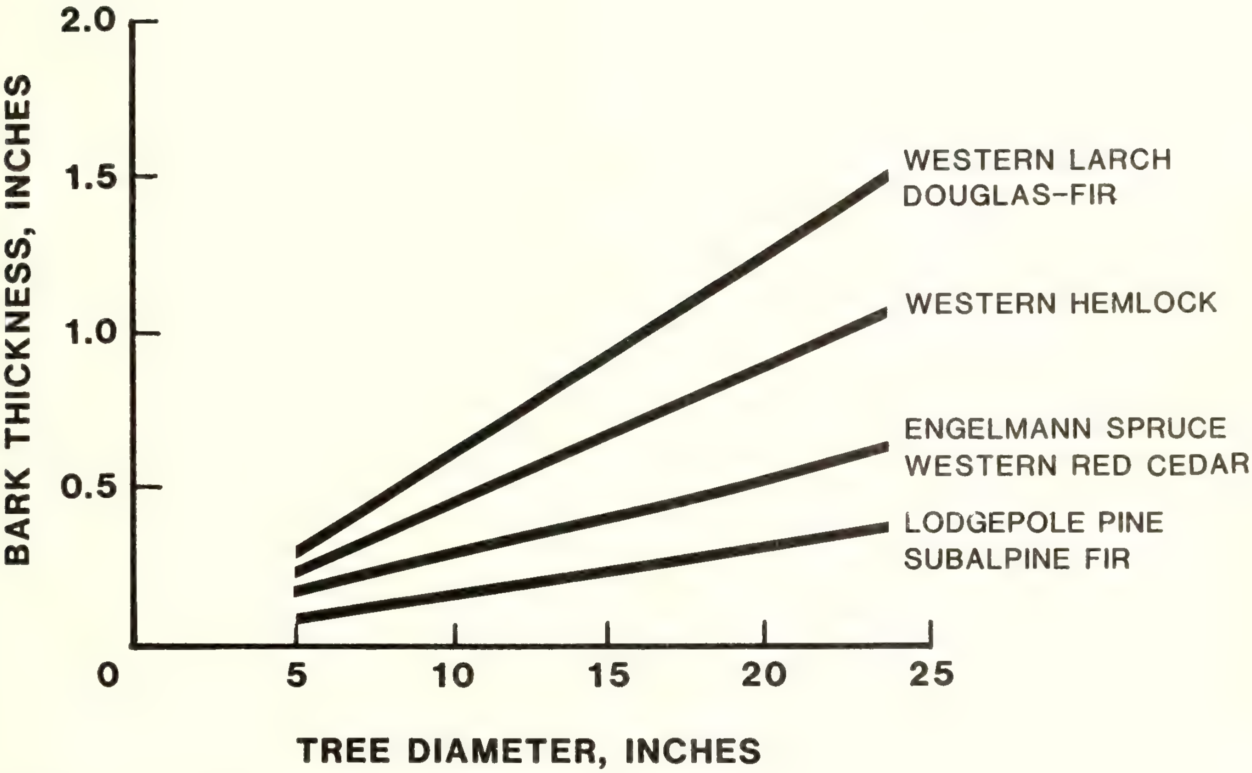


Figure 13—Bark thickness is estimated from tree diameter and species.

The model assumes that the amount of cambium damage is dependent on bark thickness. Bark thickness-tree diameter relationships for the species included in the study are given in figure 13. Only these are included in MORTALITY because the model has not yet been tested on other species. But with this in mind, you can choose the species with the bark thickness relationship that best fits the species you are concerned with or you can enter bark thickness directly.

Mortality predictions can be applied either to a stand or to an individual tree. A prediction of 30 percent mortality means that if 100 similar trees are subjected to the same fire, 30 of them are expected to die. Each tree either lives or dies. There is a 30 percent probability that an individual tree will die.

The basic assumptions of the model must be kept in mind when applying predictions of mortality to a specific area. "The model has an underlying assumption of a fire of average duration. Fires of very long duration will kill cambium through even the thickest bark, and will result in higher than predicted mortality. Thick layers of dry duff may result in long periods of smoldering even after the fire has moved through the area. Heavy concentrations of logs near trees will also result in extended duration of burning and a corresponding underprediction of mortality" (Reinhardt and Ryan 1988). On the other hand, mortality may be overpredicted if fuel is very light or patchy.

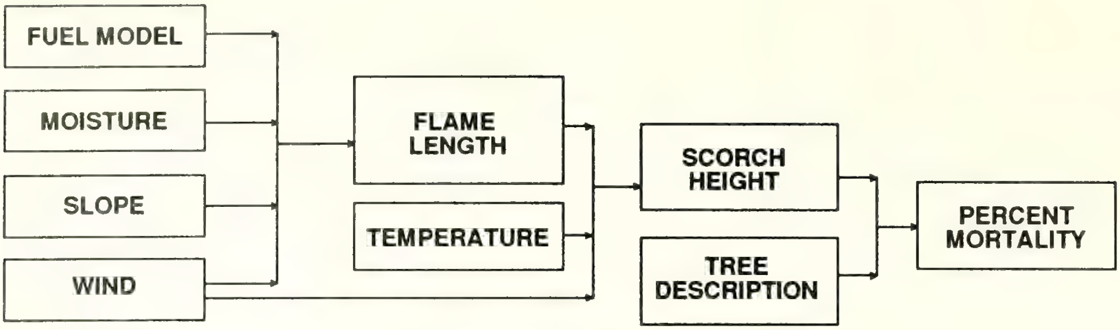


Figure 14—Information flow in MORTALITY linked to DIRECT and SCORCH. When SCORCH is linked to MORTALITY, flame length is input rather than calculated. When MORTALITY is used as an independent module, scorch height is input rather than calculated.

```
MORTALITY
 1--SCORCH HEIGHT, FT             20.0
 2--TREE HEIGHT, FT               40.0  60.0  80.0 100.0
 3--CROWN RATIO                     .9
 4--BARK THICKNESS, IN              .2    .3    .4    .5    .6
      FROM: SPECIES                3=ENGELMANN SPRUCE, WESTERN RED CEDAR
            DBH, IN                5.0  10.0  15.0  20.0  25.0

==================================================================
MORTALITY LEVEL, %                                          (V4.0)
==================================================================
  TREE    I        TREE DBH, IN
 HEIGHT   I
          I     5.     10.    15.    20.    25.
  (FT)    I------------------------------------------------------
          I
   40.    I    96.    94.    90.    86.    81.
          I
   60.    I    85.    77.    69.    59.    49.
          I
   80.    I    75.    65.    55.    44.    35.
          I
  100.    I    70.    59.    48.    38.    29.
```

Figure 15—Independent MORTALITY run. A range of values is used for tree heights and diameters; scorch height is set to a constant value. Unrealistic combinations of tree height and diameter have been crossed off.

The MORTALITY module can be used in three ways: independent, linked to SCORCH, or linked to DIRECT and SCORCH as shown in figure 3. The choice depends on the application and on available information. Scorch height can be either entered directly (MORTALITY independent) or calculated by SCORCH. Flame length can be either entered directly (SCORCH-MORTALITY link) or calculated by DIRECT (DIRECT-SCORCH-MORTALITY link).

DIRECT-SCORCH-MORTALITY link information is shown in figure 14. DIRECT calculates flame length from fuel model, moisture, wind, and slope. SCORCH uses flame length and wind from DIRECT and ambient temperature to calculate crown scorch height. MORTALITY then uses scorch height and a description of the tree to calculate mortality. This option can be used if a prediction of the level of mortality is based on predicted fire behavior. The assumptions of the models in DIRECT and SCORCH must be met, most notably the steady-state assumption for the flame length calculation (Part 1, p. 9). If flame length is controlled by the pattern of ignition or if flame length is observed, then the SCORCH-MORTALITY link option can be used, allowing you to input flame length directly. If conditions violate the assumptions of the scorch height model (for example steep slopes), or if observed scorch height is available, then MORTALITY can be used as an independent module.

A run of MORTALITY as an independent module is shown in figure 15. This example is for a range of tree heights and tree diameters. Scorch height and crown ratio are held constant. Mortality level ranges from 29 to 96 percent. Some of the combinations of tree heights and diameters are unrealistic. Rather than setting arbitrary cutoff values, we let you make the decision and cross off values as we have done in figure 15.

Figure 16 gives an example of MORTALITY linked to SCORCH. Scorch height is calculated for a range of flame lengths. Mortality level is then calculated for trees of a specified height, crown ratio, species, and diameter.

Figure 17 is an example of the complete DIRECT-SCORCH-MORTALITY link. In this case, flame length is calculated for a range of windspeeds. SCORCH gives the corresponding scorch height values, and MORTALITY gives percentage of mortality expected under these conditions.

```
SCORCH
 1--AMBIENT AIR TEMP, F ----   80.0
 2--FLAME LENGTH, FT -------    2.0    4.0    6.0    8.0   10.0
 3--MIDFLAME WINDSPEED, MI/H    2.0


               (V4.0)
          FLAME    I    CROWN
          LENGTH   I   SCORCH
                   I   HEIGHT
           (FT)    I    (FT)
                   I
          2.0      I      8.
                   I
          4.0      I     24.
                   I
          6.0      I     44.
                   I
          8.0      I     67.
                   I
         10.0      I     94.


MORTALITY-LINKED-TO-SCORCH
 1--SCORCH HEIGHT, FT ------    OUTPUT FROM SCORCH. RANGE =     8. TO   94.
 2--TREE HEIGHT, FT --------   80.0
 3--CROWN RATIO ------------     .8
 4--BARK THICKNESS, IN -----    1.3
      FROM: SPECIES             1=WESTERN LARCH, DOUGLAS-FIR
            DBH, IN            20.0


      (V4.0)
 FLAME    I   MORTALITY       CROWN
 LENGTH   I     LEVEL         VOLUME
          I                   SCORCH
  (FT)    I      (%)           (%)
          I
   2.0    I       5.           0.
          I
   4.0    I       7.          24.
          I
   6.0    I      41.          69.
          I
   8.0    I      89.          96.
          I
  10.0    I      92.         100.
```

Figure 16—MORTALITY linked to SCORCH. A range of flame lengths is input into SCORCH.

```
DIRECT
 1--FUEL MODEL                        2 -- TIMBER (GRASS AND UNDERSTORY)
 2--1-HR FUEL MOISTURE, %          4.0
 3--10-HR FUEL MOISTURE, %         6.0
 4--100-HR FUEL MOISTURE, %        6.0
 5--LIVE HERBACEOUS MOIS, %      200.0
 7--MIDFLAME WINDSPEED, MI/H       3.0    4.0    5.0
 8--TERRAIN SLOPE, %                .0
 9--DIRECTION OF WIND VECTOR        .0
10--DIRECTION OF SPREAD             .0  (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM THE WIND VECTOR


      (V4.0)
MIDFLAME I RATE OF  HEAT PER   FIRELINE  FLAME   REACTION  EFFECT.
  WIND   I SPREAD  UNIT AREA  INTENSITY  LENGTH  INTENSITY  WIND
         I
 (MI/H)  I (CH/H)  (BTU/SQFT) (BTU/FT/S)  (FT) (BTU/SQFT/M) (MI/H)
         I
   3.    I   13.       492.        116.     4.0     3567.      3.0
         I
   4.    I   20.       492.        184.     5.0     3567.      4.0
   .     I
   5.    I   30.       492.        268.     5.9     3567.      5.0


SCORCH-LINKED-TO-DIRECT
 1--AMBIENT AIR TEMP, F         75.0
 2--FLAME LENGTH, FT            OUTPUT FROM DIRECT. RANGE =    4.0 TO    5.9
 3--MIDFLAME WINDSPEED, MI/H    SAVED FROM DIRECT.  RANGE =    3.0 TO    5.0


            (V4.0)
         MIDFLAME I    CROWN
           WIND   I   SCORCH
                  I   HEIGHT
          (MI/H)  I    (FT)
                  I
          3.      I     21.
                  I
          4.      I     27.
                  I
          5.      I     33.

MORTALITY-LINKED-TO-DIRECT-AND-SCORCH
 1--SCORCH HEIGHT, FT            OUTPUT FROM SCORCH. RANGE =   21. TO   33.
 2--TREE HEIGHT, FT             50.0
 3--CROWN RATIO                   .5
 4--BARK THICKNESS, IN            .1
     FROM: SPECIES               4=LODGEPOLE PINE, SUBALPINE FIR
           DBH, IN              10.0


      (V4.0)
MIDFLAME I   MORTALITY      CROWN
  WIND   I     LEVEL        VOLUME
         I                  SCORCH
 (MI/H)  I      (%)          (%)
         I
   3.    I      68.           0.
         I
   4.    I      71.          15.
         I
   5.    I      92.          55.
```

Figure 17—MORTALITY linked to DIRECT and SCORCH. Flame length is calculated for a range of windspeeds in DIRECT.

MAXIMUM SPOTTING DISTANCE FROM WIND-DRIVEN SURFACE FIRES (SPOT)

The SPOT module of the FIRE1 program predicts the maximum distance that a firebrand will travel from torching trees, a burning pile of debris, or from a wind-driven surface fire. Use of SPOT for torching trees and burning piles is described in Part 1 (p. 47-49). The only change to those options is that additional tree species have been added to the torching tree option: slash pine, longleaf pine, pond pine, shortleaf pine, and loblolly pine (Albini 1979). The option of spotting from wind-driven surface fires (Albini 1983; Chase 1984; Morris 1987) has been added and is described here.

The option of spotting from a wind-driven surface fire can be either an independent SPOT run or linked with DIRECT. Input requirements are flame length, windspeed, and a description of the terrain. In a linked run, flame length and windspeed, are carried over from DIRECT to SPOT.

The basic assumptions that apply to all options of the spotting model are repeated here. The model is designed to predict intermediate-range spotting, not short-range spotting such as debris blowing just across a fire line. We are concerned with spots that occur far enough from the main fire to grow as independent fires. But we are not dealing with the problem of very extreme fire behavior conditions, where spotting is caused by large firebrands (even logs) being carried into the combustion column. Predictions are for **maximum** spotting distance because ideal conditions are assumed. Firebrands are assumed to be sufficiently small to be carried some distance, yet large enough to still be able to start a fire when they reach the ground. The model, however, does not address the problem of firebrands such as eucalyptus bark that literally fly through the air.

The process by which firebrands are transported from wind-driven surface fires is postulated to be that of lofting of particles by line thermals that are generated by variations in the intensity of the fire. The model is based on the assumption that the fire front is approximated by a straight line perpendicular to the direction of the wind. Predictions therefore apply to wind-driven head fires, not flanking or backing fires and not fires whose spread is influenced more by the slope than by the wind.

Use of the predictions of spotting distance from wind-driven surface fires is restricted to cases where there is no overstory. Mean cover height is set to zero. Fires burning under standing timber seldom cause spot fires at any significant distance unless the trees of the overstory become involved in the fire. The overstory is a barrier that intercepts firebrands and also interferes with development of a strong updraft that can lift firebrand particles. Some fuel models ordinarily have overstories, but are sometimes used to represent fuels without overstory cover. For example, fuel model 10 (timber litter and understory) is sometimes used to represent timber harvest debris overgrown with shrubs or other vegetation.

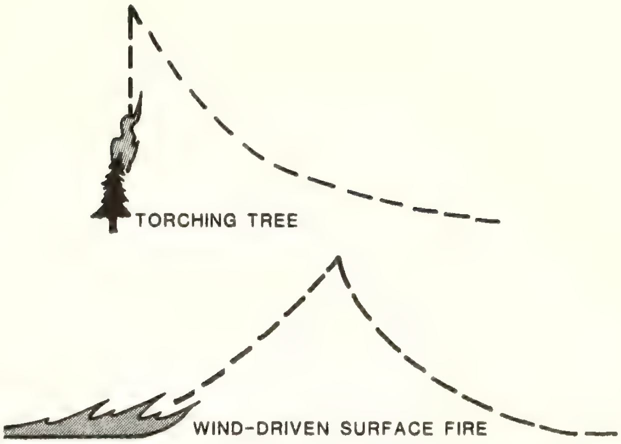


Figure 18—A firebrand from a torching tree or a burning pile is lifted straight up and then carried by the prevailing wind. This is compared to a firebrand from a wind-driven surface fire, which is carried some distance downwind from the firefront where the thermal originated before it is carried by the prevailing wind.

All three spotting source location options use the same method of calculating the distance that a firebrand is carried by the prevailing wind. The difference is in calculating initial lofting height. For the torching tree option, a description of the trees is used to calculate transitory flame characteristics. For the burning pile option, continuous flame height is entered directly. For the wind-driven surface fire option, flame length is used as an indicator of the energy in a thermal from a line fire. When the particle exits the rising thermal, it will be some distance downwind from the firefront where the thermal originated. Figure 18 illustrates the difference in the trajectories of a firebrand from a torching tree and from a wind-driven surface fire.

SPOT is offered both independently and linked to DIRECT as shown in figure 3. The independent option is included to allow the flexibility of examining the spotting distance model on its own. You are allowed to enter any value for the required input as done in figures 19 and 20 described below. But the most common use of the wind-driven surface fire option of SPOT will probably be linked to DIRECT, which calculates flame lengths, as shown in figures 21 and 22. Because flame length is not used in the torching tree or burning pile options, only the wind-driven surface fire option can be linked to DIRECT.

Figure 19 shows independent SPOT runs for two spotting source options: burning pile and wind-driven surface fire. In both cases, the mean cover height is zero. The same range of windspeeds was used in each case. And the same values were used for continuous flame height and for flame length. Notice that the predicted spotting distances are longer for the wind-driven surface fire option. This example is used to point out the difference in continuous flame height from a burning pile of debris and the flame length from a wind-driven surface fire. It also illustrates the effect of the difference in lofting mechanisms.

SPOT

1--FIREBRAND SOURCE--------	2--BURNING PILE
2--MEAN COVER HEIGHT, FT	.0
3--20-FOOT WINDSPEED, MI/H	5.0 10.0 15.0 20.0 25.0 30.0 35.0
4--RIDGE/VALLEY ELEVATION DIFFERENCE, FT	.0
11--CONTINUOUS FLAME HT, FT	4.0 8.0 12.0 16.0 20.0 24.0 28.0

MAXIMUM SPOTTING DISTANCE, MI (V4.0)

20-FT WINDSPEED (MI/H)	CONTINUOUS FLAME HEIGHT, FT 4.	8.	12.	16.	20.	24.	28.
5.	.0	.1	.1	.1	.1	.1	.1
10.	.1	.1	.1	.2	.2	.2	.2
15.	.1	.2	.2	.2	.3	.3	.3
20.	.1	.2	.3	.3	.4	.4	.5
25.	.2	.3	.3	.4	.5	.5	.6
30.	.2	.3	.4	.5	.6	.6	.7
35.	.2	.4	.5	.6	.7	.7	.8

SPOT

1--FIREBRAND SOURCE--------	3--WIND-DRIVEN SURFACE FIRE
2--MEAN COVER HEIGHT, FT	.0
3--20-FOOT WINDSPEED, MI/H	5.0 10.0 15.0 20.0 25.0 30.0 35.0
4--RIDGE/VALLEY ELEVATION DIFFERENCE, FT	.0
12--FLAME LENGTH, FT	4.0 8.0 12.0 16.0 20.0 24.0 28.0

MAXIMUM SPOTTING DISTANCE, MI (V4.0)

20-FT WINDSPEED (MI/H)	FLAME LENGTH, FT 4.	8.	12.	16.	20.	24.	28.
5.	.1	.2	.2	.2	.3	.3	.4
10.	.2	.2	.3	.4	.5	.5	.6
15.	.2	.3	.4	.5	.6	.7	.8
20.	.2	.4	.5	.6	.7	.8	.9
25.	.3	.5	.6	.7	.9	1.0	1.1
30.	.3	.5	.7	.8	1.0	1.1	1.2
35.	.4	.6	.8	.9	1.1	1.2	1.4

Figure 19—Independent SPOT runs for two spotting source options: burning pile and wind-driven surface fire.

A SPOT

1--FIREBRAND SOURCE-------- 3--WIND-DRIVEN SURFACE FIRE
2--MEAN COVER HEIGHT, FT .0
3--20-FOOT WINDSPEED, MI/H 5.0 10.0 15.0 20.0 25.0 30.0 35.0
4--RIDGE/VALLEY ELEVATION DIFFERENCE, FT 0. 1000. 2000. 3000. 4000.
5--RIDGE/VALLEY HORIZONTAL DISTANCE, MI 1.0
6--SPOTTING SOURCE LOCATION 0.-- MIDSLOPE, WINDWARD SIDE
12--FLAME LENGTH, FT 20.0

MAXIMUM SPOTTING DISTANCE, MI (V4.0)

20-FT WINDSPEED (MI/H)	RIDGE/VALLEY ELEVATIONAL DIFFERENCE, FT 0.	1000.	2000.	3000.	4000.
5.	.3	.3	.3	.3	.4
10.	.5	.5	.5	.6	.7
15.	.6	.7	.7	.8	.9
20.	.7	.8	.9	.9	1.0
25.	.9	.9	1.0	1.1	1.1
30.	1.0	1.0	1.1	1.2	1.2
35.	1.1	1.1	1.2	1.2	1.3

B SPOT

1--FIREBRAND SOURCE-------- 3--WIND-DRIVEN SURFACE FIRE
2--MEAN COVER HEIGHT, FT .0
3--20-FOOT WINDSPEED, MI/H 5.0 10.0 15.0 20.0 25.0 30.0 35.0
4--RIDGE/VALLEY ELEVATION DIFFERENCE, FT 0. 1000. 2000. 3000. 4000.
5--RIDGE/VALLEY HORIZONTAL DISTANCE, MI 1.0
6--SPOTTING SOURCE LOCATION 2.-- MIDSLOPE, LEEWARD SIDE
12--FLAME LENGTH, FT 20.0

MAXIMUM SPOTTING DISTANCE, MI (V4.0)

20-FT WINDSPEED (MI/H)	RIDGE/VALLEY ELEVATIONAL DIFFERENCE, FT 0.	1000.	2000.	3000.	4000.
5.	.3	.3	.3	.3	.3
10.	.5	.4	.4	.4	.4
15.	.6	.6	.5	.5	.5
20.	.7	.7	.7	.6	.6
25.	.9	.8	.8	.7	.7
30.	1.0	.9	.9	.8	.8
35.	1.1	1.0	1.0	.9	.8

Figure 20—Independent SPOT run for two spotting source locations.

```
DIRECT
 1--FUEL MODEL                   6 -- DORMANT BRUSH, HARDWOOD SLASH
 2--1-HR FUEL MOISTURE, %       8.0
 3--10-HR FUEL MOISTURE, %     10.0
 4--100-HR FUEL MOISTURE, %    10.0
 7--MIDFLAME WINDSPEED, MI/H    5.0  10.0  15.0  20.0  25.0
 8--TERRAIN SLOPE, %             .0
 9--DIRECTION OF WIND VECTOR     .0
10--DIRECTION OF SPREAD          .0  (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM THE WIND VECTOR
```

(V4.0)

MIDFLAME WIND (MI/H)	I	RATE OF SPREAD (CH/H)	HEAT PER UNIT AREA (BTU/SQFT)	FIRELINE INTENSITY (BTU/FT/S)	FLAME LENGTH (FT)	REACTION INTENSITY (BTU/SQFT/M)	EFFECT. WIND (MI/H)
5.	I	29.	436.	235.	5.5	1777.	5.0
10.	I	72.	436.	576.	8.4	1777.	10.0
15.	I	123.	436.	983.	10.7	1777.	15.0
20.	I	159.	436.	1268.	12.0	1777.	18.2*
25.	I	159.	436.	1268.	12.0	1777.	18.2*

* MEANS YOU HIT THE WIND LIMIT.

```
SPOT-LINKED-TO-DIRECT
 1--FIREBRAND SOURCE--------    3--WIND-DRIVEN SURFACE FIRE
 2--MEAN COVER HEIGHT, FT        .0
 3--20-FOOT WINDSPEED, MI/H    12.5  25.0  37.5  50.0  62.5
      FROM MIDFLAME WIND =      5.0  10.0  15.0  20.0  25.0
      & EXPOSED FUEL WAF =       .4
 4--RIDGE/VALLEY ELEVATION
            DIFFERENCE, FT       .0
12--FLAME LENGTH, FT            OUTPUT FROM DIRECT. RANGE=    5.5 TO   12.0
```

(V4.0)

MIDFLAME WIND (MI/H)	I	MAXIMUM SPOTTING DISTANCE (MI)
5.	I	.2
10.	I	.5
15.	I	.7
20.	I	1.0
25.	I	1.1

Figure 21—SPOT linked to DIRECT. The maximum effective windspeed is used in the flame length calculations. The actual windspeed is used in the spotting distance calculations.

A
```
DIRECT
 1--FUEL MODEL                     4 -- CHAPARRAL, 6 FT (180 CM)
 2--1-HR FUEL MOISTURE, %        5.0  10.0  15.0
 3--10-HR FUEL MOISTURE, %       6.0
 4--100-HR FUEL MOISTURE, %      6.0
 6--LIVE WOODY MOISTURE, %     150.0
 7--MIDFLAME WINDSPEED, MI/H    10.0  20.0  30.0
 8--TERRAIN SLOPE, %            20.0
 9--DIRECTION OF WIND VECTOR      .0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD           .0  (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM UPHILL

==================================================================
FLAME LENGTH, FT                                            (V4.0)
==================================================================
  1-HR   I       MIDFLAME WIND, MI/H
  MOIS   I
         I    10.     20.    30.
  (%)    I---------------------------------------------------------
         I
  5.     I   27.1    42.0   54.6
         I
 10.     I   24.4    37.8   49.1
         I
 15.     I   11.2    17.5   22.7


SPOT-LINKED-TO-DIRECT
 1--FIREBRAND SOURCE--------     3--WIND-DRIVEN SURFACE FIRE
 2--MEAN COVER HEIGHT, FT         .0
 3--20-FOOT WINDSPEED, MI/H     16.7  33.3  50.0
      FROM MIDFLAME WIND =      10.0  20.0  30.0
      & EXPOSED FUEL WAF =        .6
 4--RIDGE/VALLEY ELEVATION
           DIFFERENCE, FT     1000.0
 5--RIDGE/VALLEY HORIZONTAL
           DISTANCE, MI          1.0
 6--SPOTTING SOURCE LOCATION     0.-- MIDSLOPE, WINDWARD SIDE
12--FLAME LENGTH, FT             OUTPUT FROM DIRECT. RANGE=   11.2 TO   54.6


==================================================================
MAXIMUM SPOTTING DISTANCE, MI                               (V4.0)
==================================================================
    1-HR     I       MIDFLAME WIND, MI/H
    MOIS     I
             I    10.     20.    30.
    (%)      I----------------------------------------------------
             I
     5.      I      .9     1.8     2.8
             I
    10.      I      .8     1.7     2.6
             I
    15.      I      .5     1.0     1.5
```

Figure 22—SPOT linked to DIRECT. The direction of the wind vector is upslope in figure 22A and downslope in 22B.

```
B DIRECT
  1--FUEL MODEL                     4 -- CHAPARRAL, 6 FT (180 CM)
  2--1-HR FUEL MOISTURE, %        5.0  10.0  15.0
  3--10-HR FUEL MOISTURE, %       6.0
  4--100-HR FUEL MOISTURE, %      6.0
  6--LIVE WOODY MOISTURE, %     150.0
  7--MIDFLAME WINDSPEED, MI/H    10.0  20.0  30.0
  8--TERRAIN SLOPE, %            20.0
  9--DIRECTION OF WIND VECTOR   180.0
      DEGREES CLOCKWISE
       FROM UPHILL
 10--DIRECTION OF SPREAD          DIRECTION OF MAXIMUM SPREAD
      CALCULATIONS                  TO  BE CALCULATED
      DEGREES CLOCKWISE
       FROM UPHILL


=================================================================
FLAME LENGTH, FT                                           (V4.0)
=================================================================
   1-HR   I       MIDFLAME WIND, MI/H
   MOIS   I
          I    10.     20.     30.
   (%)    I------------------------------------------------------
          I
   5.     I   26.5    41.7    54.4
          I
  10.     I   23.8    37.5    48.9
          I
  15.     I   11.0    17.3    22.6


SPOT-LINKED-TO-DIRECT
  1--FIREBRAND SOURCE--------     3--WIND-DRIVEN SURFACE FIRE
  2--MEAN COVER HEIGHT, FT          .0
  3--20-FOOT WINDSPEED, MI/H      16.7  33.3  50.0
       FROM MIDFLAME WIND =       10.0  20.0  30.0
       & EXPOSED FUEL WAF =         .6
  4--RIDGE/VALLEY ELEVATION
            DIFFERENCE, FT      1000.0
  5--RIDGE/VALLEY HORIZONTAL
            DISTANCE, MI           1.0
  6--SPOTTING SOURCE LOCATION     2.-- MIDSLOPE, LEEWARD SIDE
 12--FLAME LENGTH, FT             OUTPUT FROM DIRECT. RANGE=   11.0 TO   54.4

=================================================================
MAXIMUM SPOTTING DISTANCE, MI                              (V4.0)
=================================================================
     1-HR     I       MIDFLAME WIND, MI/H
     MOIS     I
              I    10.     20.     30.
     (%)      I------------------------------------------------
              I
      5.      I      .7     1.7     2.7
              I
     10.      I      .7     1.6     2.5
              I
     15.      I      .4      .9     1.5
```

Figure 22 (Con.)

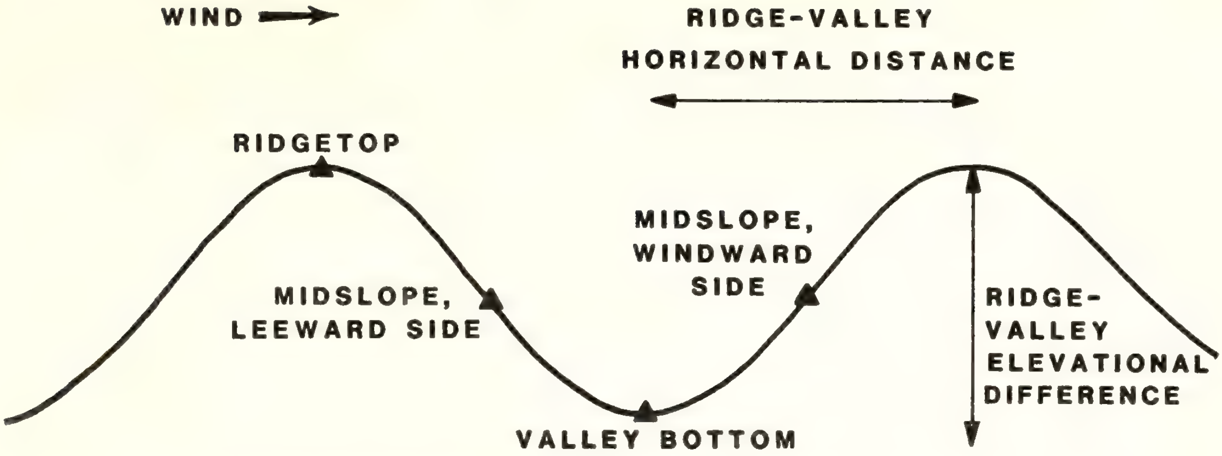


Figure 23—Mountainous terrain and spotting source location for the maximum spotting distance model.

Another use of SPOT as an independent module is to examine the effect of a change in the terrain description and spotting source location as shown in figure 20. Flame length is assigned a constant value of 20 feet. The spotting source location is midslope on the windward side for figure 20A and midslope on the leeward side for figure 20B. Recall that the spotting distance model defines the terrain with the smooth curve shown in figure 23.

Because predictions are for spotting from the head of a wind-driven fire, the link to DIRECT is allowed only when calculations are done for the direction of maximum spread as specified in line 10 input to DIRECT. In addition, spotting distance predictions are not given when the difference between the direction of the wind vector and the calculated direction of maximum spread is more than 30 degrees. In that case the fire no longer meets the assumptions of a wind-driven head fire. The direction of spread of the head fire is significantly different from the direction of the wind vector only for low windspeeds and steep slope.

The windspeed that is required by SPOT is the 20-foot windspeed while the windspeed input into DIRECT is at midflame height. The wind adjustment factor was designed to reduce 20-foot windspeed to midflame windspeed, and use in reverse is not recommended. But this is a no overstory situation and we are not concerned with slope winds. We therefore use the exposed-fuel wind adjustment factor associated with each fuel model (Part 1, p. 36) to convert the midflame windspeed from DIRECT to the 20-foot windspeed required by SPOT. As illustrated in figure 21, the list for SPOT linked to DIRECT gives the range of midflame windspeeds carried over from DIRECT, the exposed-fuel wind adjustment factor for the fuel model specified in DIRECT, and the resulting range of 20-foot windspeeds that are used in SPOT. Notice that the wind limit is reached in this example. The maximum effective windspeed of 18.2 mi/h is used in the flame length calculations, while the actual windspeed is carried over to SPOT.

Chaparral often burns under Santa Ana wind conditions, resulting in high-intensity line fires. Figure 22 shows predicted flame lengths and spotting distances for a range of fine dead fuel moistures and midflame windspeeds. In the first example, the wind is blowing upslope and the spotting source is midslope on the windward side. In the second example, wind is blowing downslope and the spotting source is midslope on the leeward side. Flame length and spotting distance predictions are, however, nearly the same. This is a wind-driven fire and the slope has very little effect. You are responsible for the consistency between the slope and wind direction input to DIRECT and the terrain description and spotting source location in SPOT. But do not be overly concerned with it. There is much variability in real world terrain as compared to the smooth curve used in the model (fig. 23). Table output from SPOT can be used to examine the effect of a range of values on the predictions.

The maximum spotting distance predictions can be used for both wildfire and for prescribed fire. About all that can be done about the occurrence of spot fires on wildfires is to predict where they might be and to watch for them. Spot fires beyond the main front can be a major factor in safety considerations and crew placement. In the planning stage of prescribed fire, spotting distance predictions can be used to determine acceptable conditions for executing the burn. Predictions can be used to place holding crews when the burn is conducted.

Albini (1983) points out that "because several elements of the model process are both speculative and not subject to direct validation, these results are to be considered tentative. Field tests of the spotting distance predictions are sought as a means of testing the utility of the model." Keep in mind that these predictions are for **maximum** spotting distances, and that most firebrands are not expected to travel that distance.

MAP DISTANCE (MAP)

MAP is an independent module in the FIRE1 program that translates calculated distances to measurements that can be plotted on a map. These may be spread distance from SIZE, maximum spotting distance from SPOT, or rate of spread from DIRECT or SITE. The map scale can be specified as either representative fraction or as inches per mile or centimeters per kilometer.

Figure 24 shows the equivalent map distance for three values of maximum spotting distance. Figure 25 shows the map spread distance for various values of rate of spread and elapsed time.

SLOPE (SLOPE, PERCENT, AND DEGREES)

A value for slope is used in the spread and intensity calculations in DIRECT and SITE. DIRECT requires direct input of the slope value. SITE either accepts the value directly or offers the option of calculating it from map measurements as described in Part 1, p. 38. We now offer the independent keyword SLOPE in the FIRE1 program for calculating slope value from topographic map measurements.

Calculation of slope steepness is based on map scale, contour interval, and the number of contour intervals over a specified map distance. Figure 26 shows calculated slope values in percentage and then degrees.

```
MAP
 1--MAP SCALE, IN/MI--------     3.00
                                 1:21120
 2--UNITS OPTION------------     2.=SPOT DISTANCE
 4--SPOT DISTANCE, MI            1.0   2.0   3.0


               (V4.0)
  SPOT           I        MAP
DISTANCE         I     SPOT FIRE
                 I     DISTANCE
  (MI)           I       (IN)
                 I
    1.           I       3.0
                 I
    2.           I       6.0
                 I
    3.           I       9.0
```

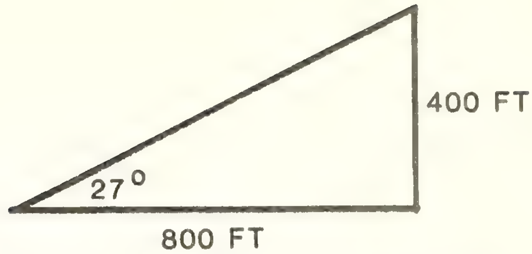
Figure 24—Example MAP run to convert spotting distance to map distance.

```
MAP
 1--MAP SCALE, IN/MI--------     2.00
                                 1:31680
 2--UNITS OPTION------------     3.=RATE OF SPREAD
 5--RATE OF SPREAD, CH/H        20.0  30.0  40.0  50.0
 6--ELAPSED TIME, HR              .5   1.0   1.5   2.0


=================================================================
MAP SPREAD DISTANCE, IN                                    (V4.0)
=================================================================
  RATE   I       ELAPSED TIME, HR
   OF    I
 SPREAD  I     .5     1.0     1.5     2.0
 (CH/H)  I--------------------------------------------------------
         I
  20.    I     .3      .5      .8     1.0
         I
  30.    I     .4      .8     1.1     1.5
         I
  40.    I     .5     1.0     1.5     2.0
         I
  50.    I     .6     1.3     1.9     2.5
```

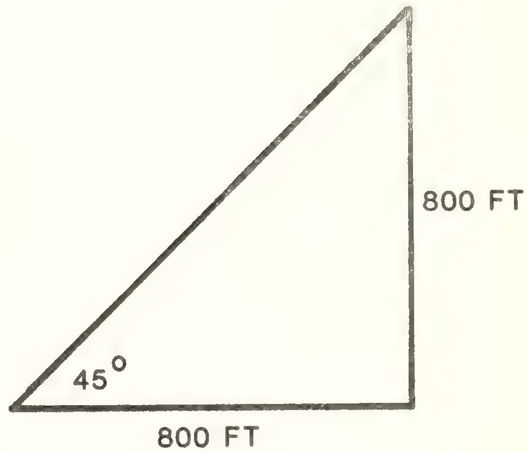
Figure 25—Example MAP run to convert rate of spread and elapsed time to map distance.

```
SLOPE
 1--MAP SCALE, IN/MI--------      2.64
                                  1:24000
 2--CONTOUR INTERVAL, FT         20.0
 3--MAP DISTANCE, IN               .4
 4--NUMBER CONTOUR INTERVALS     10.0  20.0  30.0  40.0  50.0


          (V4.0)
 NUMBER     I
   OF       I     TERRAIN          ELEVATION     HORIZONTAL
 CONTOUR    I      SLOPE             CHANGE        DISTANCE
INTERVLS    I      (%  )              (FT)           (FT)
            I
   10.      I       25.              200.           800.
            I
   20.      I       50.              400.           800.
            I
   30.      I       75.              600.           800.
            I
   40.      I      100.              800.           800.
            I
   50.      I      125.             1000.           800.


          (V4.0)
 NUMBER     I
   OF       I     TERRAIN          ELEVATION     HORIZONTAL
 CONTOUR    I      SLOPE             CHANGE        DISTANCE
INTERVLS    I      (DEG)              (FT)           (FT)
            I
   10.      I       14.              200.           800.
            I
   20.      I       27.              400.           800.
            I
   30.      I       37.              600.           800.
            I
   40.      I       45.              800.           800.
            I
   50.      I       51.             1000.           800.
```

Figure 26—Example SLOPE run, first under the mode PERCENT, then under the mode DEGREES.



$$100 \cdot \tan(27^{\circ}) = 100 \cdot \frac{400}{800} = 50\%$$



$$100 \cdot \tan(45^{\circ}) = 100 \cdot \frac{800}{800} = 100\%$$

Figure 27—A 27-degree slope is equivalent to a 50-percent slope; 45 degrees is equivalent to 100 percent.

In the earlier version of the program, slope was always specified as percentage. This is the standard in the United States, but some prefer to use degrees. The keywords PERCENT and DEGREES are used to set the mode. The default mode is PERCENT. The mode can be changed at any time, and remains in effect until it is changed again. The keyword DEGREES was entered between the two runs in figure 26.

Notice in figure 26 that a 27-degree slope is equivalent to a 50-percent slope; 45 degrees is equivalent to 100 percent. Those two cases are diagramed in figure 27.

PROBABILITY OF IGNITION (IGNITE)

The IGNITE module of the FIRE2 program allows calculation of probability that a firebrand will ignite forest fuels, given 1-hour fuel moisture, ambient air temperature, and shading of fuels due to cloud and canopy cover. An IGNITE run is shown in figure 28.

As shown in figure 3, IGNITE is an independent module in the FIRE2 program. It is, however, also automatically part of the MOISTURE module, which is described in the next section. Because the input values for IGNITE are already available from MOISTURE, probability of ignition is always given as an output value.

The equation used to calculate probability of ignition was developed by Schroeder (1969). It is based on fuel temperature and moisture content. The method of obtaining fuel temperature is handled differently in the independent module IGNITE than in the automatic probability of ignition calculations in MOISTURE. IGNITE calculations result in the same values as the table given by Rothermel (1983, p. 106). Depending on the shade category, a fixed value is added to air temperature to get fuel temperature. When probability of ignition is calculated as part of MOISTURE, fuel temperature is found using more sophisticated methods that are part of the moisture model (Rothermel and others 1986).

```
IGNITE
 1--DRY BULB TEMPERATURE, F      40.0  60.0  80.0 100.0 120.0
 2--1-HR FUEL MOISTURE, %         2.0   4.0   6.0   8.0  10.0  12.0  14.0
 3--FUEL SHADING, %              40.0


=================================================================
PROBABILITY OF IGNITION, %                                   (V4.0)
=================================================================
    DRY      I        1-HR FUEL MOISTURE, %
    BULB     I
    TEMP     I    2.      4.      6.      8.     10.     12.     14.
    (F)      I--------------------------------------------------------
             I
   40.0      I   90.     70.     50.     40.     30.     20.     10.
             I
   60.0      I   90.     70.     50.     40.     30.     20.     20.
             I
   80.0      I  100.     80.     60.     40.     30.     20.     20.
             I
  100.0      I  100.     80.     60.     50.     40.     30.     20.
             I
  120.0      I  100.     90.     70.     50.     40.     30.     20.
```

Figure 28—Example IGNITE run.

Probability of ignition is the chance that an ignition will result if a firebrand lands on flammable material and that its heat is efficiently and rapidly transferred to the fuel (Schroeder 1969). That is, for probability of ignition of 80 percent, 80 of 100 firebrands will cause ignitions, all conditions being equal and fitting the assumptions of the model. But the probability that an ember might ignite receptive fuel is only one aspect of the spotting problem. There remain questions on whether firebrands are produced, how many, what size and shape, where they land, and so on. (As described in a previous section, the SPOT module of the FIRE1 program predicts maximum spotting distance.)

Although probability of ignition of 80 percent may not tell you how many spot fires will occur, it is an indication of the severity of the situation. Probability of ignition of 80 percent certainly indicates a more severe situation than probability of ignition of 20 percent. Most mathematical models in BEHAVE give predictions in absolute terms: rate of spread in chains per hour, flame length in feet, spotting distance in miles, and so on. Probability of ignition is a percentage. But there are so many unknowns (as described above) that interpretation must largely be based on your experience. This may be in terms such as "little chance of spot fires," "probable spot fires," or "spot fires likely if firebrands are being generated."

Ignition Component (IC), a component of the National Fire Danger Rating System (Deeming and others 1977), is sometimes confused with probability of ignition. Probability of ignition includes a calculation of the heat of preignition, the net amount of heat necessary to raise the temperature of a fuel particle from its initial temperature to its ignition temperature. The model is also based on the results of a study by Blackmarr (1972), who measured the influence of moisture content on the ignitability of slash pine litter by dropping lighted matches onto fuel beds conditioned to different levels of moisture content.

Ignition Component (IC) was designed for rating fire danger. IC is based on probability of ignition. IC also includes a factor derived from the NFDRS fuel model that makes it a better indicator of human-caused fire occurrence. That factor is based on the finding that incidence of human-caused fires increases with windspeeds over 8 mi/h even though windspeed has nothing to do with the ignition process. This is explained by Haines, Main, and Crosby (1973):

> If a fire goes out quickly, there will have been a fire start, but not necessarily a **reportable** fire. Debris-burning fires offer a good example. If a firebrand from a trash burner ignites dry grass on a Missouri oak-hickory litter area during a calm afternoon, the fire should spread slowly and may be suppressed by the person maintaining the burner. On a windy day, however, the fire may escape and the operator will have to call for the assistance of a fire suppression unit.

The concept of "reportable" fires is important to rating the fire danger for a large area so that the impact on a fire suppression organization can be estimated. On the other hand, for a specific prescribed fire or wildfire, all ignitions are important. We are concerned with the probability that a firebrand will result in an ignition beyond the fire front or control line. Therefore, Ignition Component is used for fire danger rating; probability of ignition is used for fire behavior prediction.

FINE DEAD FUEL MOISTURE (MOISTURE)

The MOISTURE module of the FIRE2 program and the SITE module of the FIRE1 program are both based on the fine dead fuel moisture model (Rothermel and others 1986). Although all fine dead fuels (0- to 1/4-inch diameter) are not technically 1-hour timelag (Anderson 1985), we continue to use the currently accepted naming convention, 1-hour .

SITE allows a single calculation of rate of spread, flame length, and intensity with 1-hour moisture content as an intermediate value (Part 1, p. 8). MOISTURE is used to calculate only 1-hour moisture content, offering both table and graphic output. Because of the similarities between SITE and MOISTURE, the same input/output sheet is used for both. Items that apply only to SITE or to MOISTURE are so noted. (The line numbers for SITE have changed from those given in Part 1.)

Because the fine dead fuel moisture model is described in detail in Part 1 (p. 28-35), only an overview is given here. A general flow diagram of the model is shown in figure 29. There are five moisture initialization options to obtain an estimate of the moisture on the previous day. Choice of the option depends on available information. Two examples are direct entry of the moisture value and calculation based on up to 7 days of complete weather. An estimate of the shade is obtained from cloud cover, canopy cover, tree shape, time of year and day, latitude, elevation, and aspect. The moisture content is first calculated for the early afternoon period. Moisture can be calculated for other times of the day based on input of additional weather. A summary of the input requirements is given in Part 1 (fig. 13, p. 34). For the purposes of this model, a day goes from 1200 to 1200 (noon to noon) rather than from midnight to midnight.

MOISTURE offers two run options: burn time calculations and hourly calculations. The first option gives calculated values for the specified burn time. A range of values can be entered for one or two input values in order to produce lists or tables of output values. (SITE does not allow ranges for input variables.) The second option results in hourly values presented in the form of a list or graphs. The hourly values are intermediate values calculated each hour from 1200 to the specified burn time (see Part 1, fig. 14, p. 35). Single values must be assigned to each input for this option.

Burn Time Calculations

Of the 59 possible input values to MOISTURE, 31 are allowed to vary for the table option. You must choose one or two at a time. The choice is narrowed considerably depending on your objective. If you are interested in looking at different fire locations, you will vary site descriptions such as elevation or aspect. If you want to look at the effect of different conditions on the same fire you will vary the weather input.

When doing runs to see the effect of the change of an input value on the results, be careful about making generalizations. In one case there may be little or no effect, but in another a change in that input may be critical. Easterling and others (1986) did a sensitivity analysis of the model and concluded: "combinations of factors have more direct effect on fine fuel moisture than do single factors. Because of the importance of the interaction of minor factors, it is not recommended that any of the model inputs be dropped due to low model sensitivity."

Figure 30 is a MOISTURE run for a range of crown closure values. This example is for fuel model 2 (timber—grass and understory) and a burn time of 1500. Intermediate values from the model are given in addition to 1-hour fuel moisture. As described in a previous section, probability of ignition is always given as an output with MOISTURE because all of the required input are available. Notice the relationship between crown closure and shade. Shade is used in the calculation of fuel level temperature and relative humidity.

Figure 31 is a MOISTURE run for a range of temperature and relative humidity values at burn time. This is a prediction for fuel model 5 (2-foot brush) with no overstory and a burn time of 1500. For this example tables are printed for 1-hour moisture and for probability of ignition. Moisture values are given to a tenth of a percent so that you can see the trends in the predictions. The nearest percentage is good enough for application.

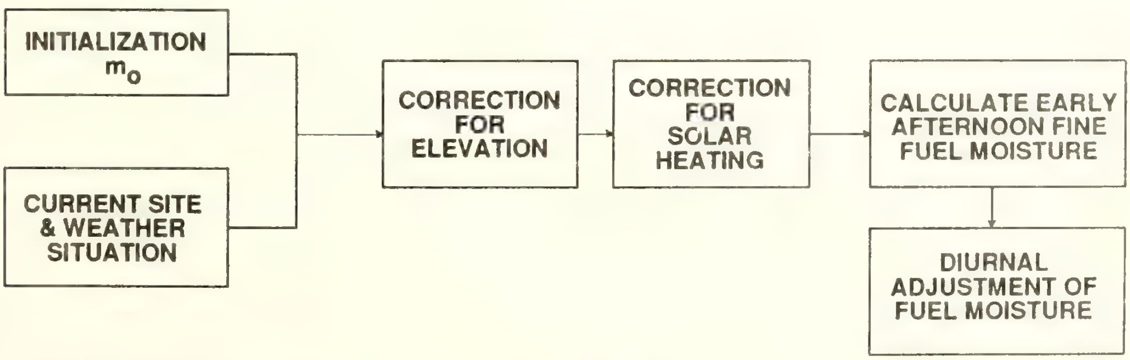


Figure 29—General flow diagram of the fine fuel moisture model that is in SITE and MOISTURE.

```
MOISTURE
 1--RUN OPTION--------------     1=BURN TIME CALCULATIONS
 2--MONTH OF BURN-----------    8.
 3--DAY OF BURN-------------   21.
 4--LATITUDE----------------   47. N
 5--BURN TIME (2400 HOURS)-- 1500.
                              508.=TIME OF SUNRISE
                             1851.=TIME OF SUNSET
 6--FUEL MODEL                  2 = TIMBER (GRASS AND UNDERSTORY)

11--TERRAIN SLOPE, %           50.0
12--ELEVATION OF FIRE
     LOCATION, FT            3000.0
13--ELEVATION OF WEATHER
      OBSERVATIONS, FT------    SAME AS FIRE LOCATION
14--ASPECT------------------    S


15--CROWN CLOSURE, %             .0  10.0  20.0  30.0  40.0  50.0  60.0
16--FOLIAGE-----------------    PRESENT
17--SHADE TOLERANCE---------    TOLERANT
18--DOMINANT TREE TYPE------    1=CONIFEROUS
19--AVERAGE TREE HEIGHT, FT    60.0
20--RATIO OF CROWN LENGTH
     TO TREE HEIGHT--------      .5
21--RATIO OF CROWN LENGTH
     TO CROWN DIAMETER-----     3.0


22--BURN DAY 1400 TEMP, F      80.0
23--BURN DAY 1400 RH, %        30.0
24--BURN DAY 1400 20-FOOT
     WIND SPEED, MI/H           5.0
25--BURN DAY 1400 CLOUD
     COVER, %                    .0
26--BURN DAY 1400 HAZINESS--    2=AVERAGE CLEAR FOREST ATMOSPHERE


    ***BURN TIME WEATHER = 1400 WEATHER***

40--EXPOSURE OF FUELS TO
      THE WIND--------------    2=PARTIALLY SHELTERED
                                 .3=WIND ADJUSTMENT FACTOR

43--MOISTURE INITIALIZATION
      CODE------------------    4=INCOMPLETE WEATHER DATA
                                  NO RAIN THE WEEK BEFORE THE BURN
                                  WEATHER PATTERN HOLDING
```

(V4.0)

CROWN CLOSURE (%)	1-HR FUEL MOIS (%)	DRY BULB TEMP (F)	AIR RH (%)	FUEL LEVEL TEMP (F)	FUEL LEVEL RH (%)	MID-FLAME WIND (MI/H)	FUEL LEVEL WIND (MI/H)	SHADE (%)	PROB OF IGN (%)
0.	4.2	80.	30.	109.	11.	1.5	1.0	0.	70.
10.	4.4	80.	30.	103.	14.	1.5	.9	17.	70.
20.	5.0	80.	30.	96.	18.	1.5	.9	33.	60.
30.	5.8	80.	30.	90.	22.	1.5	.9	48.	60.
40.	6.8	80.	30.	84.	26.	1.5	.9	61.	50.
50.	7.7	80.	30.	80.	30.	1.5	.9	72.	40.
60.	7.7	80.	30.	80.	30.	1.5	.9	81.	40.

Figure 30—Example MOISTURE run for a range of crown closure values. Note the relationship between crown closure and percent shade.

```
MOISTURE
 1--RUN OPTION--------------    1=BURN TIME CALCULATIONS
 2--MONTH OF BURN-----------    6.
 3--DAY OF BURN-------------   25.
 4--LATITUDE----------------   40. N
 5--BURN TIME (2400 HOURS)-- 1500.
                              435.=TIME OF SUNRISE
                             1925.=TIME OF SUNSET
 6--FUEL MODEL                  5 = BRUSH (2 FT)

11--TERRAIN SLOPE, %           10.0
12--ELEVATION OF FIRE
     LOCATION, FT            2500.0
13--ELEVATION OF WEATHER
      OBSERVATIONS, FT------    SAME AS FIRE LOCATION
14--ASPECT------------------    SE


15--CROWN CLOSURE, %             .0


22--BURN DAY 1400 TEMP, F      50.0  60.0  70.0  80.0  90.0 100.0
23--BURN DAY 1400 RH, %        20.0  30.0  40.0  50.0  60.0  70.0
24--BURN DAY 1400 20-FOOT
     WIND SPEED, MI/H          10.0
25--BURN DAY 1400 CLOUD
     COVER, %                    .0
26--BURN DAY 1400 HAZINESS--    1=VERY CLEAR SKY


    ***BURN TIME WEATHER = 1400 WEATHER***

40--EXPOSURE OF FUELS TO
      THE WIND--------------    1=EXPOSED
                                 .4=WIND ADJUSTMENT FACTOR

43--MOISTURE INITIALIZATION
      CODE------------------    4=INCOMPLETE WEATHER DATA
                                  NO RAIN THE WEEK BEFORE THE BURN
                                  WEATHER PATTERN HOLDING
```

Figure 31—Example MOISTURE run for ranges of burn time temperature and relative humidity.

1-HR FUEL MOISTURE, %						(V4.0)
BURN TIME TEMP (F)	BURN TIME RELATIVE HUMIDITY, %					
	20.	30.	40.	50.	60.	70.
50.	4.2	5.7	7.0	8.1	9.0	9.6
60.	4.2	4.6	5.6	6.6	7.5	8.4
70.	4.2	4.5	5.4	6.3	7.1	7.9
80.	4.2	4.4	5.3	6.0	6.8	7.5
90.	4.2	4.4	5.1	5.9	6.5	7.2
100.	4.1	4.4	5.1	5.7	6.3	6.9

PROBABILITY OF IGNITION, %						(V4.0)
BURN TIME TEMP (F)	BURN TIME RELATIVE HUMIDITY, %					
	20.	30.	40.	50.	60.	70.
50.	60.	50.	40.	40.	30.	30.
60.	70.	60.	60.	50.	40.	40.
70.	70.	70.	60.	50.	50.	40.
80.	70.	70.	60.	60.	50.	50.
90.	80.	70.	70.	60.	50.	50.
100.	80.	80.	70.	60.	60.	50.

Figure 31 (Con.)

Hourly Calculations

In order to calculate fuel moisture at burn time, calculations are done for each hour starting at 1200. The hourly calculation option of MOISTURE allows you to examine those values, in the form of either a table or a graph. Because this is essentially one set of calculations, a single value is required for each input. Because a burn day goes from 1200 to 1200, in order to see a 24-hour prediction, you must enter a burn time from the interval 1100 to 1159.

Figure 32 gives a MOISTURE run under the hourly calculation option for a burn time of 1100. One of the output choices is a table listing of the hourly values from 1200 to burn time. Any of the values on that table can be plotted. We show here only the 1-hour moisture plot. The graph is not smooth because of the resolution of the character-type graph. We have sketched in a smooth curve. Sunrise and sunset are denoted on the graph by R and S.

Appendix A includes complete runs of the MOISTURE module showing questions and user response.

RELATIVE HUMIDITY (RH)

The RH module determines relative humidity and dew point from wet bulb and dry bulb temperatures and elevation. This is an alternative to using tables such as those in the S-390 Fire Behavior Field Guide, p. 19-33 (National Wildfire Coordinating Group 1981). But because the RH module uses equations, the results may be slightly different.

Figure 33 shows tables of relative humidity and dew point for ranges of wet bulb and dry bulb temperatures. Wet bulb temperature must be greater than the dry bulb temperature as indicated by the –888. values in the upper right corner of the tables. At the lower left corner, –999. values indicate that the calculated dew point is too low for valid calculations.

```
MOISTURE
 1--RUN OPTION--------------     2=HOURLY CALCULATIONS (GRAPHIC OUTPUT)
 2--MONTH OF BURN-----------     2.
 3--DAY OF BURN-------------    10.
 4--LATITUDE----------------    33. N
 5--BURN TIME (2400 HOURS)-- 1100.
                               639.=TIME OF SUNRISE
                              1720.=TIME OF SUNSET
 6--FUEL MODEL                   7 = SOUTHERN ROUGH

11--TERRAIN SLOPE, %              .0
12--ELEVATION OF FIRE
     LOCATION, FT              300.0
13--ELEVATION OF WEATHER
      OBSERVATIONS, FT------     SAME AS FIRE LOCATION

15--CROWN CLOSURE, %            50.0
16--FOLIAGE-----------------     ABSENT
18--DOMINANT TREE TYPE------     2=DECIDUOUS
19--AVERAGE TREE HEIGHT, FT     50.0
20--RATIO OF CROWN LENGTH
     TO TREE HEIGHT--------       .5
21--RATIO OF CROWN LENGTH
     TO CROWN DIAMETER-----      1.0

22--BURN DAY 1400 TEMP, F       80.0
23--BURN DAY 1400 RH, %         60.0
24--BURN DAY 1400 20-FOOT
     WIND SPEED, MI/H            5.0
25--BURN DAY 1400 CLOUD
     COVER, %                   10.0
26--BURN DAY 1400 HAZINESS--     3=MODERATE FOREST BLUE HAZE

27--SUNSET TEMPERATURE, F       70.0
28--SUNSET RH, %                60.0
29--SUNSET 20-FOOT
     WIND SPEED, MI/H             .0
30--SUNSET CLOUD COVER, %       30.0

31--SUNRISE TEMPERATURE, F      60.0
32--SUNRISE RH, %               60.0
29--SUNRISE 20-FOOT
     WIND SPEED, MI/H             .0
34--SUNRISE CLOUD COVER, %        .0

35--BURN TIME TEMPERATURE, F    60.0
36--BURN TIME RH, %             50.0
37--BURN TIME 20-FOOT
     WIND SPEED, MI/H             .0
38--BURN TIME CLOUD COVER, %      .0
39--BURN TIME HAZINESS------     3=MODERATE FOREST BLUE HAZE
40--EXPOSURE OF FUELS TO
      THE WIND--------------     2=PARTIALLY SHELTERED
                                  .3=WIND ADJUSTMENT FACTOR

43--MOISTURE INITIALIZATION
      CODE------------------     1=1-HR FUEL MOISTURE KNOWN FOR BURN DAY -1
44--BURN DAY -1 1-HR FUEL
      MOISTURE, %-----------     9.0
```

Figure 32—Example MOISTURE run under the hourly output option. A table of hourly values and a plot of 1-hour fuel moisture are given.

(VERSION 4.0)

LOCAL SUN TIME (HR)	1-HR FUEL MOIS (%)	DRY BULB TEMP (F)	AIR RH (%)	FUEL LEVEL TEMP (F)	FUEL LEVEL RH (%)	MID-FLAME WIND (MI/H)	FUEL LEVEL WIND (MI/H)	SHADE (%)	PROB OF IGN (%)
1200	8.9	80.	60.	92.	40.	1.5	.8	14.	40.
1300	8.9	80.	60.	92.	40.	1.5	.8	14.	40.
1400	8.9	80.	60.	92.	40.	1.5	.8	14.	40.
1500	9.0	79.	60.	86.	47.	1.1	.6	22.	30.
1600	9.4	76.	60.	78.	55.	.6	.3	31.	30.
1700	9.9	72.	60.	72.	60.	.2	.1	55.	30.
1800	10.2	69.	60.	69.	60.	.0	.0	100.	30.
1900	10.6	68.	60.	68.	60.	.0	.0	100.	20.
2000	10.9	67.	60.	67.	60.	.0	.0	100.	20.
2100	11.1	66.	60.	66.	60.	.0	.0	100.	20.
2200	11.4	65.	60.	65.	60.	.0	.0	100.	20.
2300	11.6	64.	60.	64.	60.	.0	.0	100.	20.
2400	11.8	63.	60.	63.	60.	.0	.0	100.	20.
100	12.1	62.	60.	62.	60.	.0	.0	100.	20.
200	12.2	61.	60.	61.	60.	.0	.0	100.	20.
300	12.4	61.	60.	61.	60.	.0	.0	100.	20.
400	12.6	60.	60.	60.	60.	.0	.0	100.	20.
500	12.7	60.	60.	60.	60.	.0	.0	100.	20.
600	12.9	60.	60.	60.	60.	.0	.0	100.	20.
700	13.0	60.	60.	60.	60.	.0	.0	39.	20.
800	13.0	60.	59.	64.	51.	.0	.0	11.	20.
900	12.8	60.	57.	73.	37.	.0	.0	7.	20.
1000	12.2	60.	54.	81.	27.	.0	.0	5.	20.
1100	11.3	60.	50.	86.	21.	.0	.0	4.	20.

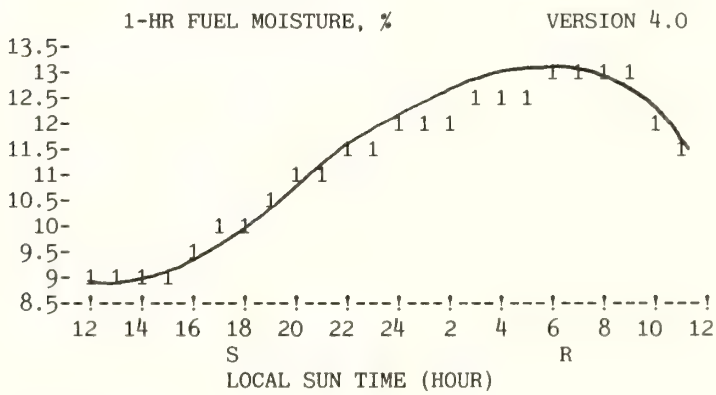


Figure 32 (Con.)

```
RH
 1--DRY BULB TEMPERATURE, F    65.0  70.0  75.0  80.0  85.0  90.0  95.0
 2--WET BULB TEMPERATURE, F    50.0  55.0  60.0  65.0  70.0  75.0  80.0
 3--ELEVATION, FT            2000.0


=================================================================
RELATIVE HUMIDITY, %                                        (V4.0)
=================================================================
    DRY       I       WET BULB TEMPERATURE, DEG F
    BULB      I
    TEMP      I    50.    55.    60.    65.    70.    75.    80.
     (F)      I----------------------------------------------------
              I
    65.       I    33.    53.    76.   100.  -888.  -888.  -888.
              I
    70.       I    21.    38.    57.    77.   100.  -888.  -888.
              I
    75.       I    12.    26.    42.    59.    79.   100.  -888.
              I
    80.       I     5.    17.    30.    45.    62.    80.   100.
              I
    85.       I  -999.    10.    22.    34.    48.    63.    81.
              I
    90.       I  -999.     5.    15.    25.    37.    50.    65.
              I
    95.       I  -999.     1.    10.    19.    29.    40.    53.

    -888 = WET BULB TEMPERATURE GREATER THAN DRY BULB.

    -999 = DEW POINT IS LESS THAN -40 DEGREES.


=================================================================
DEW POINT, F                                                (V4.0)
=================================================================
    DRY       I       WET BULB TEMPERATURE, DEG F
    BULB      I
    TEMP      I    50.    55.    60.    65.    70.    75.    80.
     (F)      I----------------------------------------------------
              I
    65.       I    36.    48.    57.    65.  -888.  -888.  -888.
              I
    70.       I    29.    43.    54.    63.    70.  -888.  -888.
              I
    75.       I    19.    38.    50.    60.    68.    75.  -888.
              I
    80.       I     4.    32.    46.    57.    66.    73.    80.
              I
    85.       I  -999.    23.    42.    54.    63.    71.    78.
              I
    90.       I  -999.    11.    36.    50.    60.    69.    77.
              I
    95.       I  -999.   -14.    29.    46.    58.    67.    75.

    -888 = WET BULB TEMPERATURE GREATER THAN DRY BULB.

    -999 = DEW POINT IS LESS THAN -40 DEGREES.
```

Figure 33—Example RH run.

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APPENDIX A—ANNOTATED RUNS OF THE FIRE1 AND FIRE2 PROGRAMS OF BEHAVE.

Fire behavior prediction models that have been added to BEHAVE are illustrated in the body of the paper with sample input and output from the programs. This appendix provides complete user sessions for the FIRE1 and FIRE2 programs, with all of the interaction between the user and the computer. Basic operation is emphasized in the sample run in appendix A of Part 1 (Andrews 1986); that information is still valid. This run is used to illustrate the changes and additions to the programs.

Lines that begin with a > (the prompt symbol) were typed by the user. All others were printed by the computer. The prompt symbol may be different on another computer. (The Forest Service Data General system does not give a prompt.)

Gaining access to the BEHAVE programs and printing log files are functions of the computer being used and therefore are not described in this manual.

Contents

```
WELCOME TO THE BEHAVE SYSTEM
  BURN SUBSYSTEM
    FIRE1 PROGRAM: VERSION 4.0 -- MAY 1989

DEVELOPED BY:  THE FIRE BEHAVIOR RESEARCH WORK UNIT
               INTERMOUNTAIN FIRE SCIENCES LABORATORY
               MISSOULA, MONTANA

YOU ARE RESPONSIBLE FOR SUPPLYING VALID INPUT AND FOR
  CORRECTLY INTERPRETING THE FIRE BEHAVIOR PREDICTIONS.
```

This is important.

```
ASSUMPTIONS, LIMITATIONS, AND APPLICATION OF MATHEMATICAL
  MODELS USED IN THIS PROGRAM ARE IN:
  Andrews, Patricia L. "BEHAVE: Fire behavior prediction and
    fuel modeling system--BURN subsystem, Part 1", INT-GTR-194, 1986
  Andrews, Patricia L., and Chase, Carolyn H. "BEHAVE: Fire
    behavior prediction and fuel modeling system--BURN
    subsystem, Part 2", INT-GTR-260, 1989

(PRESS CARRIAGE RETURN TO CONTINUE)
>

PAUSE OPTION AND ENGLISH UNITS SET.
  SLOPE MEASUREMENT IN PERCENT.
WHEN YOU ARE READY TO CONTINUE AFTER THE PROMPT
SYMBOL IS PRINTED WITHOUT A QUESTION,
PRESS THE CARRIAGE RETURN KEY.

TYPE 'CUSTOM' IF YOU ARE GOING TO USE CUSTOM FUEL MODELS.

FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SCORCH,SPOT,
      MORTALITY,MAP,SLOPE,DISPATCH,CUSTOM,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS,QUIT
>status
```

The program recognizes only upper case input. Use your shift lock key.

```
****ALL UPPER CASE PLEASE****

FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SCORCH,SPOT,
      MORTALITY,MAP,SLOPE,DISPATCH,CUSTOM,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS,QUIT
>STAT
```

These are new keywords.

The program checks only the first four letters of keywords.

```
**** FIRE1 STATUS REQUEST ****
     PROMPT MODE    :  WORDY
     DISPLAY MODE   :  PAUSE
     LOG FILE NAME  :  UNDECLARED
     LOG FUNCTION   :  OFF
     FUEL FILE NAME:   UNDECLARED
     DISPLAY UNITS  :  ENGLISH
     SLOPE UNITS    :  PERCENT
```

Default values for mode keywords.

```
FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SCORCH,SPOT,
      MORTALITY,MAP,SLOPE,DISPATCH,CUSTOM,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS,QUIT
>COMMENT

NO LOG FILE CURRENTLY ACTIVE.  REMEMBER THAT THIS
  COMMENT APPEARS ONLY ON YOUR TERMINAL--NOT IN ANY LOG FILE.

ENTER TEXT FOR DOCUMENTATION.
  USE A CARRIAGE RETURN AT THE END OF EACH LINE.
  TO TERMINATE, ENTER (ON A NEW LINE) **
  FOLLOWED BY A CARRIAGE RETURN.
```

On non-printing terminals, COMMENT is useful only if the LOG option is activated. However, the program gives you the choice of continuing if you are using a printing terminal.

```
****************************************************************************
COMMENT:
>**
****************************************************************************
```

Let's terminate the comment and specify a log file.

```
FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SCORCH,SPOT,
      MORTALITY,MAP,SLOPE,DISPATCH,CUSTOM,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS,QUIT
>LOG

WHAT FILE NAME DO YOU WANT TO USE? (12 CHARACTERS MAX)
  FIRST CHARACTER MUST BE ALPHABETIC.  FOLLOW THE NAMING
  CONVENTION FOR YOUR COMPUTER.
>LOGFIL

LOG IS ON.
THE NAME OF YOUR LOGFILE IS: LOGFIL
```

This is a new file. Specifying an existing file will be covered later. Once a file has been attached to the run, it remains the same until the run is terminated.

```
FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SCORCH,SPOT,
      MORTALITY,MAP,SLOPE,DISPATCH,CUSTOM,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS,QUIT
>STATUS
```

```
**** FIRE1 STATUS REQUEST ****
    PROMPT MODE    :  WORDY
    DISPLAY MODE   :  PAUSE
    LOG FILE NAME  :  LOGFIL
    LOG FUNCTION   :  ON
    FUEL FILE NAME :  UNDECLARED
    DISPLAY UNITS  :  ENGLISH
    SLOPE UNITS    :  PERCENT
```

A log file has been declared.

The log function can be turned on and off at any time during the run.

```
FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SCORCH,SPOT,
      MORTALITY,MAP,SLOPE,DISPATCH,CUSTOM,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS,QUIT
>COMMENT

ENTER TEXT FOR DOCUMENTATION.
  USE A CARRIAGE RETURN AT THE END OF EACH LINE.
  TO TERMINATE, ENTER (ON A NEW LINE) **
  FOLLOWED BY A CARRIAGE RETURN.
```

Characters typed after the 80th and before a return will be lost (even if the cursor automatically moves to the next line).

```
****************************************************************************
COMMENT:
>AN FBA MIGHT USE THE COMMENT KEYWORD TO LABEL A DIRECT RUN WITH
>      1.  FIRE NAME
>      2.  PROJECTION TIME AND DATE
>**
****************************************************************************
```

One suggestion for the use of COMMENT. Use it however you wish.

```
FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SCORCH,SPOT,
      MORTALITY,MAP,SLOPE,DISPATCH,CUSTOM,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS,QUIT
>SLOPE

SLOPE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>INPUT

(1) MAP SCALE OPTION ? 1-2 OR QUIT
      1=REPRESENTATIVE FRACTION
      2=INCHES PER MILE
>2

(1) MAP SCALE, IN/MI ? .1-20
>2.64
```

Input to the hundredths place is OK <u>only for map scale and precipitation amount.</u>

```
 *(2) CONTOUR INTERVAL, FT ? 10-500
>40

 *(3) MAP DISTANCE, IN ? .1-10
>1

 *(4) NUMBER OF CONTOUR INTERVALS ? 1-100
>5,9,2

 THE FOLLOWING VALUES WILL BE USED
    5.0    7.0    9.0
 OK ? Y-N
>Y

 SLOPE KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>LIST


 SLOPE
  1--MAP SCALE, IN/MI--------     2.64
                                  1: 24000.
  2--CONTOUR INTERVAL, FT ---    40.0
  3--MAP DISTANCE, IN -------     1.0
  4--NUMBER CONTOUR INTERVALS     5.0   7.0   9.0

 SLOPE KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>RUN

          (V4.0)
 NUMBER      I
   OF        I   TERRAIN         ELEVATION     HORIZONTAL
 CONTOUR     I    SLOPE            CHANGE       DISTANCE
 INTERVLS    I    (%  )             (FT)          (FT)
             I
    5.0      I     10.              200.         2000.
             I
    7.0      I     14.              280.         2000.
             I
    9.0      I     18.              360.         2000.
```

* before an input prompt indicates that a range of input is OK.

The version number of the program is printed with all RUN output.

```
SLOPE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>DEGREES

CURRENT UNITS SYSTEM: ENGLISH.   SLOPE IS IN DEGREES

SLOPE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>RUN


         (V4.0)
 NUMBER     I
   OF       I    TERRAIN        ELEVATION     HORIZONTAL
CONTOUR     I     SLOPE           CHANGE       DISTANCE
INTERVLS    I     (DEG)            (FT)          (FT)
            I
   5.0      I       6.             200.         2000.
            I
   7.0      I       8.             280.         2000.
            I
   9.0      I      10.             360.         2000.

SLOPE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>PERCENT

CURRENT UNITS SYSTEM: ENGLISH.   SLOPE IS IN PERCENT

SLOPE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>QUIT

FINISH SLOPE -- BACK TO FIRE1
```

Let's look at slope in degrees.

Compare these values with those marked in the previous run.

Back to our usual units.

```
 FIRE1 KEYWORD?
 ENTER DIRECT,SITE,SIZE,CONTAIN,SCORCH,SPOT,
       MORTALITY,MAP,SLOPE,DISPATCH,CUSTOM,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS,QUIT
>DIRECT


 DIRECT KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
       SIZE,SCORCH
>INPUT

 (1) FUEL MODEL ? 0-99 OR QUIT
       (ENTER 0 FOR TWO FUEL MODEL CONCEPT INPUT.)
>5

 *(2) 1-HR FUEL MOISTURE, % ? 1-60
>5

 *(3) 10-HR FUEL MOISTURE, % ? 1-60
>6

 *(6) LIVE WOODY MOISTURE, % ? 30-300
>90

 *(7) MIDFLAME WINDSPEED, MI/H ? 0-99
>1,5,1

 THE FOLLOWING VALUES WILL BE USED
    1.0     2.0     3.0     4.0     5.0
 OK ? Y-N
>Y

 *(8) TERRAIN SLOPE, % ? 0-100
>40,100,10

 THE FOLLOWING VALUES WILL BE USED
   40.0   50.0   60.0   70.0   80.0   90.0  100.0
 OK ? Y-N
>Y

 *(9) DIRECTION OF WIND VECTOR,
       DEGREES CLOCKWISE FROM UPHILL ? 0-360
>40

 (10) DO YOU WANT FIRE BEHAVIOR PREDICTIONS FOR
      THE DIRECTION OF MAXIMUM SPREAD ? Y-N
>Y
```

Link to SCORCH and SPOT is not allowed with the two-fuel-model concept.

You can INPUT in English units ...

```
 DIRECT KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>METRIC
```

then switch to metric to run.

```
 CURRENT UNITS SYSTEM:  METRIC.   SLOPE IS IN PERCENT

 DIRECT KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>LIST
```

Note that METRIC and ENGLISH do not affect slope units.

```
 DIRECT
  1--FUEL MODEL -------------      5 -- BRUSH, 2 FT (60 CM)
  2--1-HR FUEL MOISTURE, % --    5.0
  3--10-HR FUEL MOISTURE, % -    6.0
  6--LIVE WOODY MOISTURE, % -   90.0
  7--MIDFLAME WINDSPEED, KM/H    1.6    3.2    4.8    6.4    8.0
  8--TERRAIN SLOPE, % -------   40.0   50.0   60.0   70.0   80.0   90.0  100.0
  9--DIRECTION OF WIND VECTOR   40.0
     DEGREES CLOCKWISE
      FROM UPHILL
 10--DIRECTION OF SPREAD ----   DIRECTION OF MAXIMUM SPREAD
     CALCULATIONS                 TO  BE CALCULATED
     DEGREES CLOCKWISE
      FROM UPHILL
```

Non-integer values are due to conversion to metric units.

Note for later reference.

```
 DIRECT KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>RUN

 TABLE VARIABLE ? 0-7

  0=NO MORE TABLES       4=FLAME LENGTH
  1=RATE OF SPREAD       5=REACTION INTENSITY
  2=HEAT PER UNIT AREA   6=EFFECTIVE WINDSPEED
  3=FIRELINE INTENSITY   7=DIRECTION OF MAX SPREAD
>4
```

```
=================================================================
FLAME LENGTH, M                                            (V4.0)
=================================================================
MIDFLAME I        TERRAIN SLOPE, %
  WIND   I
         I   40.0   50.0   60.0   70.0   80.0   90.0  100.0
 (KM/H)  I--------------------------------------------------------
         I
  1.6    I    1.3    1.5    1.7    1.9    2.1    2.3    2.5
         I
  3.2    I    1.5    1.7    1.8    2.0    2.2    2.4    2.6
         I
  4.8    I    1.7    1.9    2.0    2.2    2.4    2.5    2.7
         I
  6.4    I    2.0    2.1    2.2    2.4    2.5    2.7    2.9
         I
  8.0    I    2.2    2.3    2.4    2.5    2.7    2.8    3.0
```

The flame lengths are in meters.

```
 TABLE VARIABLE ? 0-7

  0=NO MORE TABLES       4=FLAME LENGTH
  1=RATE OF SPREAD       5=REACTION INTENSITY
  2=HEAT PER UNIT AREA   6=EFFECTIVE WINDSPEED
  3=FIRELINE INTENSITY   7=DIRECTION OF MAX SPREAD
>0


 IF YOU WANT TO CONTINUE WITH THE AREA AND PERIMETER CALCULATIONS,
   TYPE 'SIZE'
 IF YOU WANT TO CONTINUE WITH SCORCH HEIGHT CALCULATIONS,
   TYPE 'SCORCH'
 IF YOU WANT TO CONTINUE WITH SPOTTING DISTANCE FROM
   A WIND-DRIVEN SURFACE FIRE, TYPE 'SPOT'

 DIRECT KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
       SIZE,SCORCH,SPOT
>ENGLISH
```

Back to English units.

```
 CURRENT UNITS SYSTEM:  ENGLISH.  SLOPE IS IN PERCENT.

 DIRECT KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
       SIZE,SCORCH,SPOT
>RUN
```

```
TABLE VARIABLE ? 0-7

  0=NO MORE TABLES       4=FLAME LENGTH
  1=RATE OF SPREAD       5=REACTION INTENSITY
  2=HEAT PER UNIT AREA   6=EFFECTIVE WINDSPEED
  3=FIRELINE INTENSITY   7=DIRECTION OF MAX SPREAD
>7


=================================================================
DIRECTION OF MAXIMUM SPREAD, DEG                            (V4.0)
=================================================================
MIDFLAME I        TERRAIN SLOPE, %
  WIND   I
         I    40.0   50.0   60.0   70.0   80.0   90.0  100.0
 (MI/H)  I-------------------------------------------------------
         I
 1.0     I    12.     8.     6.     5.     4.     3.     2.
         I
 2.0     I    21.    17.    13.    10.     8.     7.     6.
         I
 3.0     I    27.    22.    19.    16.    13.    11.     9.
         I
 4.0     I    30.    26.    23.    20.    17.    15.    13.
         I
 5.0     I    32.    29.    26.    23.    20.    18.    16.
```

This will be referred to later.

```
TABLE VARIABLE ? 0-7

  0=NO MORE TABLES       4=FLAME LENGTH
  1=RATE OF SPREAD       5=REACTION INTENSITY
  2=HEAT PER UNIT AREA   6=EFFECTIVE WINDSPEED
  3=FIRELINE INTENSITY   7=DIRECTION OF MAX SPREAD
>0


IF YOU WANT TO CONTINUE WITH THE AREA AND PERIMETER CALCULATIONS,
  TYPE 'SIZE'
IF YOU WANT TO CONTINUE WITH SCORCH HEIGHT CALCULATIONS,
  TYPE 'SCORCH'
IF YOU WANT TO CONTINUE WITH SPOTTING DISTANCE FROM
  A WIND-DRIVEN SURFACE FIRE, TYPE 'SPOT'
```

Link to SPOT is allowed only for a head fire.

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
      SIZE,SCORCH,SPOT
>SPOT
```

```
SPOT-LINKED-TO-DIRECT KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>INPUT
```

Keyword requests and lists are labeled to help you keep track of where you are.

```
 *(4) RIDGE/VALLEY ELEVATIONAL DIFFERENCE, FT ? 0-4000
>1000

 *(5) RIDGE/VALLEY HORIZONTAL DISTANCE, MI ? 0-4
>1.

 (6) SPOTTING SOURCE LOCATION ? 0-3
      0=MIDSLOPE, WINDWARD SIDE
      1=VALLEY BOTTOM
      2=MIDSLOPE,LEEWARD SIDE
      3=RIDGETOP
>1

 SPOT-LINKED-TO-DIRECT KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>LIST
```

only option available for SPOT linked to DIRECT

To emphasize that wind-driven surface fire calculations apply only when there is no significant timber cover

```
 SPOT-LINKED-TO-DIRECT
  1--FIREBRAND SOURCE--------     3--WIND-DRIVEN SURFACE FIRE
  2--MEAN COVER HEIGHT, FT --      .0
  3--20-FOOT WINDSPEED, MI/H      2.5    5.0    7.5   10.0   12.5
       FROM MIDFLAME WIND =       1.0    2.0    3.0    4.0    5.0
       & EXPOSED FUEL WAF =        .4
  4--RIDGE/VALLEY ELEVATION
           DIFFERENCE, FT -- 1000.0
  5--RIDGE/VALLEY HORIZONTAL
           DISTANCE, MI ----      1.0
  6--SPOTTING SOURCE LOCATION     1.-- VALLEY BOTTOM
 12--FLAME LENGTH, FT -------     OUTPUT FROM DIRECT. RANGE=    4.2 TO    9.9
```

saved from DIRECT

```
 SPOT-LINKED-TO-DIRECT KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>RUN
```

20-ft wind is calculated from midflame wind input in DIRECT and the wind adjustment factor for the fuel model from DIRECT (does not use effective windspeed)

SPOT input lines 1,2,3,12 cannot be changed in linked runs.

```
============================================================================
MAXIMUM SPOTTING DISTANCE, MI                                         (V4.0)
============================================================================
  MIDFLAME    I        TERRAIN SLOPE, %
    WIND      I
              I    40.0    50.0    60.0    70.0    80.0    90.0   100.0
   (MI/H)     I-------------------------------------------------------------
              I
    1.0       I      .1    -1.0    -1.0    -1.0    -1.0    -1.0    -1.0
              I
    2.0       I      .1      .1      .1      .1    -1.0    -1.0    -1.0
              I
    3.0       I      .1      .2      .2      .2      .2      .2    -1.0
              I
    4.0       I      .2      .2      .2      .2      .2      .2      .3
              I
    5.0       I      .2      .3      .3      .3      .3      .3      .3

    -1.=THIS IS NOT A WIND-DRIVEN HEAD FIRE.
          THE DIRECTION OF MAXIMUM SPREAD IS MORE THEN 30
          DEGREES FROM THE DIRECTION OF THE WIND VECTOR.
```

Note! See line 7 of DIRECT listing and direction of max spread output.

```
SPOT-LINKED-TO-DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>QUIT

FINISH SPOT LINKED TO DIRECT--BACK TO DIRECT

DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>QUIT

FINISH DIRECT --BACK TO FIRE1
```

QUIT all the way back to FIRE1

```
FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SCORCH,SPOT,
      MORTALITY,MAP,SLOPE,DISPATCH,CUSTOM,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS,QUIT
>MORTALITY
```

and run MORTALITY as an independent module.

```
 MORTALITY KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>INPUT

 *(1) SCORCH HEIGHT, FT ? 1-200 OR QUIT
>30

 *(2) TREE HEIGHT, FT ? 20-200
>20,110,45

 THE FOLLOWING VALUES WILL BE USED
   20.0   65.0  110.0
 OK ? Y-N
>Y

 *(3) CROWN RATIO ? .1-1
>.8

 (4) BARK THICKNESS OPTION ? 1-2
       1=DETERMINE BY SPECIES AND DBH
       2=DIRECT ENTRY
>1

 (4) TREE SPECIES ? 1-5
       1=WESTERN LARCH, DOUGLAS-FIR
       2=WESTERN HEMLOCK
       3=ENGELMANN SPRUCE, WESTERN RED CEDAR
       4=LODGEPOLE PINE, SUBALPINE FIR
       5=NONE OF THESE
>3

 *(4) TREE DBH, IN ? 5-50
>5,25,10

 THE FOLLOWING VALUES WILL BE USED
    5.0   15.0   25.0
 OK ? Y-N
>Y

 MORTALITY KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>LIST
```

Bark thickness is the MORTALITY input. These are the options for getting the values in.

These choices result in a prompt for bark thickness —

or choose a species with bark thickness similar to the one you are interested in

```
MORTALITY
 1--SCORCH HEIGHT, FT ------    30.0
 2--TREE HEIGHT, FT --------    20.0   65.0 110.0
 3--CROWN RATIO ------------      .8
 4--BARK THICKNESS, IN -----      .2     .4     .6
      FROM: SPECIES              3=ENGELMANN SPRUCE, WESTERN RED CEDAR
            DBH, IN              5.0   15.0   25.0
```

These values are calculated from species and DBH.

```
MORTALITY KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>RUN

TABLE VARIABLE ? 0-2

  0=NO MORE TABLES
  1=MORTALITY LEVEL
  2=CROWN VOLUME SCORCH
>1


==================================================================
MORTALITY LEVEL, %                                          (V4.0)
==================================================================
  TREE    I       TREE DBH, IN
 HEIGHT   I
          I    5.0   15.0   25.0
  (FT)    I-------------------------------------------------------
          I
  20.0    I   100.    99.    97.
          I
  65.0    I    90.    78.    62.
          I
 110.0    I    68.    46.    28.

TABLE VARIABLE ? 0-2

  0=NO MORE TABLES
  1=MORTALITY LEVEL
  2=CROWN VOLUME SCORCH
>0

MORTALITY KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>QUIT

FINISH MORTALITY--BACK TO FIRE1
```

Calculations are made for all input combinations specified. The user must determine which combinations are unrealistic.

```
 FIRE1 KEYWORD?
 ENTER DIRECT,SITE,SIZE,CONTAIN,SCORCH,SPOT,
       MORTALITY,MAP,SLOPE,DISPATCH,CUSTOM,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS,QUIT
>SCORCH

 SCORCH KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>INPUT

 *(1) AMBIENT AIR TEMPERATURE, F ? 33-120 OR QUIT
>85

 *(2) FLAME LENGTH, FT ? .1-100
>8

 *(3) MIDFLAME WINDSPEED, MI/H ? 0-99
>5

 SCORCH KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>LIST


 SCORCH
  1--AMBIENT AIR TEMP, F ----   85.0
  2--FLAME LENGTH, FT -------    8.0
  3--MIDFLAME WINDSPEED, MI/H    5.0

 SCORCH KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>RUN


     (VERSION 4.0)

     CROWN SCORCH HEIGHT, FT              67.
```

SCORCH independent

```
 SCORCH KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
       MORTALITY
>MORTALITY
```

Mortality linked to scorch

```
 MORTALITY-LINKED-TO-SCORCH KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>INPUT

 *(2) TREE HEIGHT, FT ? 20-200
>20,110,45

 THE FOLLOWING VALUES WILL BE USED
   20.0   65.0  110.0
 OK ? Y-N
>Y

 *(3) CROWN RATIO ? .1-1
>.8

 (4) BARK THICKNESS OPTION ? 1-2
       1=DETERMINE BY SPECIES AND DBH
       2=DIRECT ENTRY
>2

 (4) BARK THICKNESS, IN ? .1-5
>.2,.6,.2
```

Enter bark thickness directly this time.

```
 THE FOLLOWING VALUES WILL BE USED
     .2     .4     .6
 OK ? Y-N
>Y

 MORTALITY-LINKED-TO-SCORCH KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>LIST


 MORTALITY-LINKED-TO-SCORCH
  1--SCORCH HEIGHT, FT ------    OUTPUT FROM SCORCH =  67.
  2--TREE HEIGHT, FT --------   20.0  65.0 110.0
  3--CROWN RATIO ------------      .8
  4--BARK THICKNESS, IN -----      .2    .4    .6
       (DIRECT ENTRY)
```

This value has been carried over from SCORCH.

```
 MORTALITY-LINKED-TO-SCORCH KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>RUN

 TABLE VARIABLE ? 0-2

   0=NO MORE TABLES
   1=MORTALITY LEVEL
   2=CROWN VOLUME SCORCH
>1


 ==================================================================
 MORTALITY LEVEL, %                                          (V4.0)
 ==================================================================
   TREE   I       TREE DBH, IN
  HEIGHT  I
          I    5.0   15.0   25.0
   (FT)   I--------------------------------------------------------
          I
   20.0   I    99.    99.    98.
          I
   65.0   I    99.    99.    98.
          I
  110.0   I    97.    94.    88.

 TABLE VARIABLE ? 0-2

   0=NO MORE TABLES
   1=MORTALITY LEVEL
   2=CROWN VOLUME SCORCH
>0

 MORTALITY-LINKED-TO-SCORCH KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>QUIT

 FINISH MORTALITY LINKED TO SCORCH--BACK TO SCORCH

 SCORCH KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
       MORTALITY
>QUIT

 FINISH SCORCH --BACK TO FIRE1
```

```
 FIRE1 KEYWORD?
 ENTER DIRECT,SITE,SIZE,CONTAIN,SCORCH,SPOT,
       MORTALITY,MAP,SLOPE,DISPATCH,CUSTOM,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS,QUIT
>DIRECT

 DIRECT KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>INPUT

 (1) FUEL MODEL ? 0-99 OR QUIT
       (ENTER 0 FOR TWO FUEL MODEL CONCEPT INPUT.)
>10

 *(2) 1-HR FUEL MOISTURE, % ? 1-60
>5,11,2

 THE FOLLOWING VALUES WILL BE USED
    5.0    7.0    9.0   11.0
 OK ? Y-N
>Y

 *(3) 10-HR FUEL MOISTURE, % ? 1-60
>7

 *(4) 100-HR FUEL MOISTURE, % ? 1-60
>8

 *(6) LIVE WOODY MOISTURE, % ? 30-300
>150

 *(7) MIDFLAME WINDSPEED, MI/H ? 0-99
>4,14,2

 THE FOLLOWING VALUES WILL BE USED
    4.0    6.0    8.0   10.0   12.0   14.0
 OK ? Y-N
>Y

 *(8) TERRAIN SLOPE, % ? 0-100
>15

 *(9) DIRECTION OF WIND VECTOR,
       DEGREES CLOCKWISE FROM UPHILL ? 0-360
>0
```

DIRECT-SCORCH-MORTALITY
linked run

```
 (10) DO YOU WANT FIRE BEHAVIOR PREDICTIONS FOR
      THE DIRECTION OF MAXIMUM SPREAD ? Y-N
>Y

 DIRECT KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>LIST


 DIRECT
  1--FUEL MODEL -------------    10 -- TIMBER (LITTER AND UNDERSTORY)
  2--1-HR FUEL MOISTURE, % --    5.0   7.0   9.0  11.0
  3--10-HR FUEL MOISTURE, % -    7.0
  4--100-HR FUEL MOISTURE, %     8.0
  6--LIVE WOODY MOISTURE, % -  150.0
  7--MIDFLAME WINDSPEED, MI/H    4.0   6.0   8.0  10.0  12.0  14.0
  8--TERRAIN SLOPE, % -------   15.0
  9--DIRECTION OF WIND VECTOR     .0
      DEGREES CLOCKWISE
       FROM UPHILL
 10--DIRECTION OF SPREAD ----     .0  (DIRECTION OF MAX SPREAD)
     CALCULATIONS
      DEGREES CLOCKWISE
       FROM UPHILL

 DIRECT KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS
>RUN

 TABLE VARIABLE ? 0-6

  0=NO MORE TABLES      4=FLAME LENGTH
  1=RATE OF SPREAD      5=REACTION INTENSITY
  2=HEAT PER UNIT AREA  6=EFFECTIVE WINDSPEED
  3=FIRELINE INTENSITY
>4
```

```
==================================================================
FLAME LENGTH, FT                                            (V4.0)
==================================================================
  1-HR    I       MIDFLAME WIND, MI/H
  MOIS    I
          I     4.0     6.0     8.0    10.0    12.0    14.0
   (%)    I-------------------------------------------------------
          I
 5.0      I    4.1     5.2     6.1     7.0     7.9     8.7
          I
 7.0      I    3.8     4.8     5.7     6.6     7.4     8.2
          I
 9.0      I    3.7     4.6     5.5     6.3     7.1     7.8
          I
11.0      I    3.6     4.5     5.3     6.1     6.9     7.6


TABLE VARIABLE ? 0-6

 0=NO MORE TABLES       4=FLAME LENGTH
 1=RATE OF SPREAD       5=REACTION INTENSITY
 2=HEAT PER UNIT AREA   6=EFFECTIVE WINDSPEED
 3=FIRELINE INTENSITY
>0

IF YOU WANT TO CONTINUE WITH THE AREA AND PERIMETER CALCULATIONS,
  TYPE 'SIZE'
IF YOU WANT TO CONTINUE WITH SCORCH HEIGHT CALCULATIONS,
  TYPE 'SCORCH'
IF YOU WANT TO CONTINUE WITH SPOTTING DISTANCE FROM
  A WIND-DRIVEN SURFACE FIRE, TYPE 'SPOT'

DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
      SIZE,SCORCH,SPOT
>SCORCH

SCORCH-LINKED-TO-DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>INPUT

*(1) AMBIENT AIR TEMPERATURE, F ? 33-120 OR QUIT
>75
```

The only SCORCH input in a linked run.

```
SCORCH-LINKED-TO-DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>LIST
```

These values are carried over from DIRECT.

```
SCORCH-LINKED-TO-DIRECT
 1--AMBIENT AIR TEMP, F ----   75.0
 2--FLAME LENGTH, FT -------   OUTPUT FROM DIRECT. RANGE =    3.6 TO    8.7
 3--MIDFLAME WINDSPEED, MI/H - SAVED FROM DIRECT.  RANGE =    4.0 TO   14.0

SCORCH-LINKED-TO-DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>RUN


=====================================================================
CROWN SCORCH HEIGHT, FT                                        (V4.0)
=====================================================================
    1-HR     I       MIDFLAME WIND, MI/H
    MOIS     I
             I     4.0     6.0     8.0    10.0    12.0    14.0
    (%)      I-------------------------------------------------------
             I
    5.0      I    19.     23.     26.     28.     29.     31.
             I
    7.0      I    17.     20.     22.     24.     25.     26.
             I
    9.0      I    16.     18.     20.     22.     23.     24.
             I
   11.0      I    15.     17.     19.     20.     21.     22.


SCORCH-LINKED-TO-DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
      MORTALITY
>MORTALITY

MORTALITY-LINKED-TO-DIRECT-AND-SCORCH KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>INPUT
```

```
 *(2) TREE HEIGHT, FT ? 20-200
>50

 *(3) CROWN RATIO ? .1-1
>.6

 (4) BARK THICKNESS OPTION ? 1-2
      1=DETERMINE BY SPECIES AND DBH
      2=DIRECT ENTRY
>2

 *(4) BARK THICKNESS, IN ? .1-5
>.1

 MORTALITY-LINKED-TO-DIRECT-AND-SCORCH KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>LIST


 MORTALITY-LINKED-TO-DIRECT-AND-SCORCH
  1--SCORCH HEIGHT, FT ------    OUTPUT FROM SCORCH. RANGE =   15. TO   31.
  2--TREE HEIGHT, FT --------   50.0
  3--CROWN RATIO ------------     .6
  4--BARK THICKNESS, IN -----     .1
       (DIRECT ENTRY)

 MORTALITY-LINKED-TO-DIRECT-AND-SCORCH KEYWORD?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>RUN

 TABLE VARIABLE ? 0-2

   0=NO MORE TABLES
   1=MORTALITY LEVEL
   2=CROWN VOLUME SCORCH
>1
```

```
==================================================================
MORTALITY LEVEL, %                                          (V4.0)
==================================================================
  1-HR   I       MIDFLAME WIND, MI/H
  MOIS   I
         I   4.0    6.0    8.0   10.0   12.0   14.0
  (%)    I--------------------------------------------------------
         I
   5.0   I   73.    77.    84.    89.    92.    94.
         I
   7.0   I   73.    73.    75.    79.    82.    85.
         I
   9.0   I   73.    73.    73.    74.    76.    78.
         I
  11.0   I   73.    73.    73.    73.    74.    75.


TABLE VARIABLE ? 0-2

  0=NO MORE TABLES
  1=MORTALITY LEVEL
  2=CROWN VOLUME SCORCH
>0

MORTALITY-LINKED-TO-DIRECT-AND-SCORCH KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
>QUIT

FINISH MORTALITY LINKED TO SCORCH AND DIRECT--BACK TO SCORCH

SCORCH-LINKED-TO-DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
      MORTALITY
>QUIT

FINISH SCORCH - BACK TO DIRECT


DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS
      SIZE,SCORCH,SPOT
>QUIT

FINISH DIRECT -- BACK TO FIRE1
```

```
 FIRE1 KEYWORD?
 ENTER DIRECT,SITE,SIZE,CONTAIN,SCORCH,SPOT,
       MORTALITY,MAP,SLOPE,DISPATCH,CUSTOM,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS,QUIT
>QUIT

 DO YOU  R E A L L Y  WANT TO TERMINATE THIS RUN? Y-N
>Y

 PART OF THIS RUN MAY HAVE BEEN LOGGED.
 THE FILE NAME IS: LOGFIL
 PRINT THE FILE NOW AND DELETE IT.


 FIRE1 RUN TERMINATED.
 *******************************
```

A reminder of your log file name and encouragement to delete it when you no longer need it. You are responsible for your own file maintenance.

```
WELCOME TO THE BEHAVE SYSTEM
  BURN SUBSYSTEM
    FIRE2 PROGRAM: VERSION 4.0 -- MAY 1989

DEVELOPED BY:  THE FIRE BEHAVIOR RESEARCH WORK UNIT
               INTERMOUNTAIN FIRE SCIENCES LABORATORY
               MISSOULA, MONTANA

YOU ARE RESPONSIBLE FOR SUPPLYING VALID INPUT AND FOR
  CORRECTLY INTERPRETING THE FIRE BEHAVIOR PREDICTIONS.

ASSUMPTIONS, LIMITATIONS, AND APPLICATION OF MATHEMATICAL
  MODELS USED IN THIS PROGRAM ARE IN:
  Andrews, Patricia L. "BEHAVE: Fire behavior prediction and
    fuel modeling system--BURN subsystem, Part 1", INT-GTR-194, 1986.
  Andrews, Patricia L., and Chase, Carolyn H. "BEHAVE: Fire
    behavior prediction and fuel modeling system--BURN
    subsystem, Part 2", INT-GTR-260, 1989.

(PRESS RETURN TO CONTINUE)
>


PAUSE OPTION AND ENGLISH UNITS SET.
  SLOPE MEASUREMENT IS IN PERCENT.
WHEN YOU ARE READY TO CONTINUE AFTER THE PROMPT SYMBOL IS
PRINTED WITHOUT A QUESTION, PRESS THE CARRIAGE RETURN KEY.

TYPE 'CUSTOM' IF YOU ARE GOING TO USE CUSTOM FUEL MODELS.

FIRE2 KEYWORD ?
ENTER IGNITE,MOISTURE,RH,CUSTOM,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY,HELP,STATUS,QUIT
>LOG

WHAT FILE NAME DO YOU WANT TO USE? (12 CHARACTERS MAX)
  FIRST CHARACTER MUST BE ALPHABETIC. FOLLOW THE NAMING
  CONVENTION FOR YOUR COMPUTER.
>LOGFIL

LOG FILE "LOGFIL" EXISTS.  DO YOU WANT TO
    1=APPEND TO FILE "LOGFIL"
    2=CHANGE TO ANOTHER LOG FILE
    3=DELETE "LOGFIL" AND START A NEW FILE WITH THE SAME NAME
>1

LOG IS ON.
THE NAME OF YOUR LOGFILE IS:  LOGFIL
```

We used this file for the FIRE 1 run and did not delete. You must make a choice.

```
 FIRE2 KEYWORD ?
 ENTER IGNITE,MOISTURE,RH,CUSTOM,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS,QUIT
>MOISTURE

 MOISTURE KEYWORD ?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY HELP,STATUS
>INPUT
```

Graphic option

```
 REMINDER:  'BURN DAY' STARTS AT NOON AND CONTINUES FOR 24
            HOURS.  ALL INPUTS ARE IN REFERENCE TO 'BURN DAY.'

 (1) RUN OPTION ? 1-2 OR QUIT
     1 = BURN TIME CALCULATIONS
     2 = HOURLY CALCULATIONS (GRAPHIC OUTPUT)
>2
```

Line 1 is used in MOISTURE but not in SITE.

Lines 7-10 are used in SITE but not in MOISTURE.

```
 (2) MONTH OF BURN ? 1-12
>7

 (3) DAY OF BURN ? 1-31
>25

 (4) LATITUDE, DEG. ? 0 TO 90
>46

 (4) NORTH OR SOUTH OF THE EQUATOR ? N-S
>N
```

There is no latitude estimation by state abbreviation in MOISTURE. MOISTURE and SITE can now handle southern latitudes.

```
 SUNSET  = 1926.
 SUNRISE =  433.

 (5) BURN TIME ? 0000-2359
>1150
```

To obtain a 24-hour diurnal prediction, you must use a burn time of 1100 to 1159 (because of the definition of burn day).

```
 (6) FUEL MODEL ? 1-99
>5
```

No 2-fuel-model concept is allowed in MOISTURE. Fuel models are used only to provide a fuel depth for wind adjustment purposes. Custom fuel models are allowed.

```
 (11) TERRAIN SLOPE, % ? 0 TO 100
>10
```

There are no slope helps in MOISTURE as there are in SITE.

```
 (12) ELEVATION OF FIRE LOCATION, FT ? 0 TO 12000
>1000

 (13) ARE WEATHER OBSERVATIONS AT THE SAME ELEVATION
      AS THE FIRE ? Y-N
>Y
```

The same information is obtained as before, but using a new format. This applies in both SITE and MOISTURE.

```
(14) ASPECT ? N,NE,E,SE,S,SW,W,NW
>SE

(15) CROWN CLOSURE, % ? 0-100 OR QUIT
  (ENTER THE CLOSURE AS IF THERE WERE FOLIAGE)
>0

(22) BURN DAY 1400 TEMPERATURE, F ? 33 TO 120 OR QUIT
>85

(23) BURN DAY 1400 RELATIVE HUMIDITY, % ? 1 TO 100
>20

(24) BURN DAY 1400 20-FOOT WINDSPEED, MI/H ? 0 TO 99
>5

(25) BURN DAY 1400 CLOUD COVER, % ? 0 TO 100
>0

(26) BURN DAY 1400 HAZINESS ? 1-4
       1=VERY CLEAR SKY
       2=AVERAGE CLEAR FOREST ATMOSPHERE
       3=MODERATE FOREST BLUE HAZE
       4=DENSE HAZE
>1

(27) SUNSET TEMPERATURE, F ? 33 TO 120
>68

(28) SUNSET RELATIVE HUMIDITY, % ? 1 TO 100
>30

(29) SUNSET 20-FOOT WINDSPEED, MI/H ? 0 TO 99
>0

(30) SUNSET CLOUD COVER, % ? 0 TO 100
>0

(31) SUNRISE TEMPERATURE, F ? 33 TO 120
>57

(32) SUNRISE RELATIVE HUMIDITY, % ? 1 TO 100
>35

(33) SUNRISE 20-FOOT WINDSPEED, MI/H ? 0 TO 99
>0

(34) SUNRISE CLOUD COVER, % ? 0 TO 100
>0

(35) BURN TIME TEMPERATURE, F ? 33 TO 120
>70
```

There is no estimation of relative humidity for sunset, sunrise, burn time in MOISTURE (this capability is still available in SITE).

```
 (36) BURN TIME RELATIVE HUMIDITY, % ? 1 TO 100
>30

 (37) BURN TIME 20-FOOT WINDSPEED, MI/H ? 0 TO 99
>5

 (38) BURN TIME CLOUD COVER, % ? 0 TO 100
>0

 (39) BURN TIME HAZINESS ? 1-4
        1=VERY CLEAR SKY
        2=AVERAGE CLEAR FOREST ATMOSPHERE
        3=MODERATE FOREST BLUE HAZE
        4=DENSE HAZE
>1

 (40) EXPOSURE TO WIND ? 1-5
    1 = EXPOSED
    2 = PARTIALLY SHELTERED
    3 = FULLY SHELTERED--OPEN STAND
    4 = FULLY SHELTERED--DENSE STAND
    5 = DIRECT ENTRY OF WIND ADJUSTMENT FACTOR
>1
```

In MOISTURE, there is no help in determining exposure to wind as there is in SITE. Option 5 is new to SITE.

```
 (43) MOISTURE INITIALIZATION OPTION ? 1-5 OR QUIT

        1=1-HR FUEL MOISTURE KNOWN FOR BURN DAY -1

        2=COMPLETE WEATHER DATA FOR 3 TO 7 DAYS

        3=INCOMPLETE WEATHER DATA
          RAIN THE WEEK BEFORE THE BURN

        4=INCOMPLETE WEATHER DATA
          NO RAIN THE WEEK BEFORE THE BURN
          WEATHER PATTERN HOLDING
          (NO ADDITIONAL INPUT)

        5=INCOMPLETE WEATHER DATA
          WEATHER PATTERN CHANGING
>3

 (51) NUMBER OF DAYS BEFORE THE BURN THAT RAIN OCCURRED ? 1-7
>5

 (52) RAIN AMOUNT, INCHES ? .01 TO 4
>.09

 (53) 1400 TEMPERATURE ON THE DAY IT RAINED, F ? 33 TO 120
>70
```

Precipitation amounts can be put in to the nearest hundredth (both SITE and MOISTURE). SITE (English) units for this input have been changed to inches.

```
(54) SKY CONDITION FROM THE DAY IT RAINED TIL BURN DAY ? 1-3
     1=CLEAR
     2=CLOUDY
     3=PARTLY CLOUDY
>1

MOISTURE KEYWORD ?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY HELP,STATUS
>LIST


MOISTURE
 1--RUN OPTION--------------    2=HOURLY CALCULATIONS (GRAPHIC OUTPUT)
 2--MONTH OF BURN-----------    7.
 3--DAY OF BURN-------------   25.
 4--LATITUDE----------------   46. N
 5--BURN TIME (2400 HOURS)-- 1150.
                              433.=TIME OF SUNRISE
                             1926.=TIME OF SUNSET
 6--FUEL MODEL                  5 = BRUSH (2 FT)

11--TERRAIN SLOPE, % -------   10.0
12--ELEVATION OF FIRE
     LOCATION, FT ---------- 1000.0
13--ELEVATION OF WEATHER
      OBSERVATIONS, FT------    SAME AS FIRE LOCATION
14--ASPECT------------------    SE

>

15--CROWN CLOSURE, % -------     .0

>

22--BURN DAY 1400 TEMP, F --   85.0
23--BURN DAY 1400 RH, % ----   20.0
24--BURN DAY 1400 20-FOOT
     WIND SPEED, MI/H ------    5.0
25--BURN DAY 1400 CLOUD
     COVER, % --------------     .0
26--BURN DAY 1400 HAZINESS--    1=VERY CLEAR SKY


27--SUNSET TEMPERATURE, F --   68.0
28--SUNSET RH, % -----------   30.0
29--SUNSET 20-FOOT
     WIND SPEED, MI/H ------     .0
30--SUNSET CLOUD COVER, % --     .0

>
```

```
31--SUNRISE TEMPERATURE, F -   57.0
32--SUNRISE RH, % ----------   35.0
29--SUNRISE 20-FOOT
     WIND SPEED, MI/H ------     .0
34--SUNRISE CLOUD COVER, % -     .0


35--BURN TIME TEMPERATURE, F   70.0
36--BURN TIME RH, % --------   30.0
37--BURN TIME 20-FOOT
     WIND SPEED, MI/H ------    5.0
38--BURN TIME CLOUD COVER, %     .0
39--BURN TIME HAZINESS------    1=VERY CLEAR SKY
40--EXPOSURE OF FUELS TO
      THE WIND--------------    1=EXPOSED
                                 .4=WIND ADJUSTMENT FACTOR
>

43--MOISTURE INITIALIZATION
      CODE------------------    3=INCOMPLETE WEATHER DATA
                                  RAIN THE WEEK BEFORE THE BURN
51--NUMBER OF DAYS BEFORE
    BURN THAT RAIN OCCURRED     5.0
52--RAIN AMOUNT, INCHES ----     .09
53--1400 TEMPERATURE ON
     THE DAY IT RAINED, F --   70.0
54--SKY CONDITION AFTER THE
      DAY IT RAINED---------    1=CLEAR

MOISTURE KEYWORD ?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY HELP,STATUS
>RUN

PLOT VARIABLE ? 0-11

0=NO MORE GRAPHS             6=MIDFLAME WIND
1=1-HR FUEL MOISTURE         7=FUEL LEVEL WIND
2=DRY BULB TEMPERATURE       8=SHADE PERCENT
3=AIR RH                     9=PROBABILITY OF IGNITION
4=FUEL LEVEL TEMPERATURE    10=TABULAR OUTPUT
5=FUEL LEVEL RH             11=2 OR MORE PARAMETERS
                                 ON SAME AXES
>10
```

Tabular output provides the values of all 9 parameters (1-9) each hour from noon until burn time.

(VERSION 4.0)

LOCAL SUN TIME (HR)	1-HR FUEL MOIS (%)	DRY BULB TEMP (F)	AIR RH (%)	FUEL LEVEL TEMP (F)	FUEL LEVEL RH (%)	MID-FLAME WIND (MI/H)	FUEL LEVEL WIND (MI/H)	SHADE (%)	PROB OF IGN (%)
1200	3.9	85.	20.	113.	8.	2.0	1.1	0.	80.
1300	3.9	85.	20.	113.	8.	2.0	1.1	0.	80.
1400	3.9	85.	20.	113.	8.	2.0	1.1	0.	80.
1500	3.2	84.	20.	108.	9.	1.6	.9	0.	80.
1600	3.1	82.	22.	101.	12.	1.3	.7	0.	80.
1700	3.1	79.	24.	91.	16.	.9	.5	0.	80.
1800	3.3	75.	26.	79.	23.	.5	.3	0.	80.
1900	3.6	70.	29.	70.	29.	.2	.1	0.	70.
2000	3.9	67.	30.	67.	30.	.0	.0	100.	70.
2100	4.1	65.	31.	65.	31.	.0	.0	100.	60.
2200	4.4	63.	32.	63.	32.	.0	.0	100.	60.
2300	4.6	62.	33.	62.	33.	.0	.0	100.	60.
2400	4.8	60.	34.	60.	34.	.0	.0	100.	60.
100	5.1	59.	34.	59.	34.	.0	.0	100.	50.
200	5.3	58.	35.	58.	35.	.0	.0	100.	50.
300	5.6	57.	35.	57.	35.	.0	.0	100.	50.
400	5.8	57.	35.	57.	35.	.0	.0	100.	50.

Probability of ignition in MOISTURE uses the predicted fuel level temperature in the prob. of ign. equations instead of the fuel temperature estimate based on air temp. and shade as in the prob. of ign. table. The result is rounded to the nearest 10%.

(VERSION 4.0)

LOCAL SUN TIME (HR)	1-HR FUEL MOIS (%)	DRY BULB TEMP (F)	AIR RH (%)	FUEL LEVEL TEMP (F)	FUEL LEVEL RH (%)	MID-FLAME WIND (MI/H)	FUEL LEVEL WIND (MI/H)	SHADE (%)	PROB OF IGN (%)
500	6.0	57.	35.	57.	35.	.1	.1	0.	50.
600	6.2	58.	35.	66.	27.	.4	.2	0.	50.
700	6.2	59.	34.	76.	20.	.7	.4	0.	50.
800	5.9	60.	34.	85.	15.	.9	.5	0.	50.
900	5.3	63.	33.	93.	12.	1.2	.7	0.	60.
1000	4.7	65.	32.	98.	11.	1.5	.9	0.	70.
1100	4.0	68.	31.	101.	10.	1.8	1.0	0.	70.
1150	4.0	70.	30.	103.	10.	2.0	1.1	0.	70.

The headings are repeated on the terminal for your convenience. They are omitted in log files.

```
PLOT VARIABLE ? 0-11

0=NO MORE GRAPHS            6=MIDFLAME WIND
1=1-HR FUEL MOISTURE        7=FUEL LEVEL WIND
2=DRY BULB TEMPERATURE      8=SHADE PERCENT
3=AIR RH                    9=PROBABILITY OF IGNITION
4=FUEL LEVEL TEMPERATURE   10=TABULAR OUTPUT
5=FUEL LEVEL RH            11=2 OR MORE PARAMETERS
                                ON SAME AXES
>1

SCALE OPTION ? 1-2
    1 = USE THE CALCULATED Y-AXIS RANGE
    2 = SET THE Y-AXIS RANGE
>1
```

The calculated y-axis range spreads the plot vertically as much as possible.

Parameter being plotted

```
      1-HR FUEL MOISTURE, %                 VERSION 4.0
6.5-
   !                                     1 1
  6-                                   1
   !                                 1       1
5.5-                               1
   !                             1             1
  5-                           1
   !                         1                   1
4.5-                       1
   !                     1
  4- 1 1 1             1                           1
   !                 1
3.5-               1
   !       1     1
  3--!---!---1-1-!---!---!---!---!---!---!---!---!---!---!
    12  14  16  18  20  22  24   2   4   6   8  10  12
                    S                 R
                LOCAL SUN TIME (HOUR)
>
```

1 corresponds to the list number from above for this parameter

S = sunset R = sunrise

```
PLOT VARIABLE ? 0-11

0=NO MORE GRAPHS              6=MIDFLAME WIND
1=1-HR FUEL MOISTURE          7=FUEL LEVEL WIND
2=DRY BULB TEMPERATURE        8=SHADE PERCENT
3=AIR RH                      9=PROBABILITY OF IGNITION
4=FUEL LEVEL TEMPERATURE     10=TABULAR OUTPUT
5=FUEL LEVEL RH              11=2 OR MORE PARAMETERS
                                  ON SAME AXES
>11
```

More than 2 or 3 becomes too busy to be useful.

```
PARAMETER NO. 1?
0=NO MORE PARAMETERS         5=FUEL LEVEL RH
1=1-HR FUEL MOISTURE         6=MIDFLAME WIND
2=DRY BULB TEMPERATURE       7=FUEL LEVEL WIND
3=AIR RH                     8=SHADE PERCENT
4=FUEL LEVEL TEMPERATURE     9=PROBABILITY OF IGNITION
>2

PARAMETER NO. 2?
0=NO MORE PARAMETERS         5=FUEL LEVEL RH
1=1-HR FUEL MOISTURE         6=MIDFLAME WIND
2=DRY BULB TEMPERATURE       7=FUEL LEVEL WIND
3=AIR RH                     8=SHADE PERCENT
4=FUEL LEVEL TEMPERATURE     9=PROBABILITY OF IGNITION
>4
```

```
PARAMETER NO. 3?
0=NO MORE PARAMETERS        5=FUEL LEVEL RH
1=1-HR FUEL MOISTURE        6=MIDFLAME WIND
2=DRY BULB TEMPERATURE      7=FUEL LEVEL WIND
3=AIR RH                    8=SHADE PERCENT
4=FUEL LEVEL TEMPERATURE    9=PROBABILITY OF IGNITION
>0

SCALE OPTION ? 1-2
    1 = USE THE CALCULATED Y-AXIS RANGE
    2 = SET THE Y-AXIS RANGE
>2

Y-AXIS MINIMUM ? 0-200
>50

Y-AXIS MAXIMUM ? 0-200
>115
```

Let's set our own y-axis range this time.

The key to the plotted parameters corresponds to the list.

```
     1=1-HR   2=DBULB  3=RH     4=FTEMP          VERSION 4.0
     5=FRH    6=MWIND  7=FWIND  8=SHADE  9=PI
  120-
     ! 4 4 4
  110-       4
     !
  100-         4                                   4 4
     !
   90-           4
     ! 2 2 2 2                                 4
   80-         2 2 4
     !             2                         4
   70-               4                               2
     !                 4 4 4               4     2 2
   60-                       4 4 4 4       2 2 2
     !                               4 4 4
   50--!---!---!---!---!---!---!---!---!---!---!---!---!
      12  14  16  18  20  22  24   2   4   6   8  10  12
                      S                 R
                  LOCAL SUN TIME (HOUR)
>
```

Imagine the smooth curve sketched in. The steps in the line are due to the resolution of the character display.

Fuel temperature (4) plotted on top of air temperature here, so the 2's disappeared.

```
PLOT VARIABLE ? 0-11

0=NO MORE GRAPHS            6=MIDFLAME WIND
1=1-HR FUEL MOISTURE        7=FUEL LEVEL WIND
2=DRY BULB TEMPERATURE      8=SHADE PERCENT
3=AIR RH                    9=PROBABILITY OF IGNITION
4=FUEL LEVEL TEMPERATURE   10=TABULAR OUTPUT
5=FUEL LEVEL RH            11=2 OR MORE PARAMETERS
                                ON SAME AXES
>0
```

```
 MOISTURE KEYWORD ?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY HELP,STATUS
>INPUT


 REMINDER:  'BURN DAY' STARTS AT NOON AND CONTINUES FOR 24
            HOURS.  ALL INPUTS ARE IN REFERENCE TO 'BURN DAY.'

 (1) RUN OPTION ? 1-2 OR QUIT
     1 = BURN TIME CALCULATIONS
     2 = HOURLY CALCULATIONS (GRAPHIC OUTPUT)
>1
```

Run option must be 1 for ranging input to be acceptable. If using CHANGE, be sure to change line 1 first.

```
 (2) MONTH OF BURN ? 1-12
>5

 (3) DAY OF BURN ? 1-31
>30

 (4) LATITUDE, DEG. ? 0 TO 90
>40

 (4) NORTH OR SOUTH OF THE EQUATOR ? N-S
>N

 SUNSET  = 1918.
 SUNRISE =  442.

 (5) BURN TIME ? 0000-2359
>1500

 (6) FUEL MODEL ? 1-99
>2

 *(11) TERRAIN SLOPE, % ? 0 TO 100
>10

 *(12) ELEVATION OF FIRE LOCATION, FT ? 0 TO 12000
>4500
```

Note the * to indicate which lines allow ranges for option 1. The star did not appear in the last run when run option =2.

```
 (13) ARE WEATHER OBSERVATIONS AT THE SAME ELEVATION
       AS THE FIRE ? Y-N
>Y

 (14) DO YOU WANT CALCULATIONS FOR ALL ASPECTS ? Y-N
>Y
```

— The choice is all or only one.

```
 (15) CROWN CLOSURE, % ? 0-100 OR QUIT
   (ENTER THE CLOSURE AS IF THERE WERE FOLIAGE)
>10
```

```
 (16) IS FOLIAGE PRESENT ? Y-N
>Y

 (17) ARE THE TREES IN THE STAND SHADE TOLERANT? Y-N
>N

 (18) DOMINANT TREE TYPE ? 1-2
      1 = CONIFEROUS
      2 = DECIDUOUS
>1

 *(19) AVERAGE TREE HEIGHT, FT ? 10 TO 300
>50

 *(20) RATIO OF CROWN LENGTH TO TREE HEIGHT ? .1-1
>.7

 *(21) RATIO OF CROWN LENGTH TO CROWN DIAMETER ? .2-7
>3

 *(22) BURN DAY 1400 TEMPERATURE, F ? 33 TO 120 OR QUIT
>60,72,2

 THE FOLLOWING VALUES WILL BE USED
   60.0   62.0   64.0   66.0   68.0   70.0   72.0
 OK ? Y-N
>Y

 *(23) BURN DAY 1400 RELATIVE HUMIDITY, % ? 1 TO 100
>40

 *(24) BURN DAY 1400 20-FOOT WINDSPEED, MI/H ? 0 TO 99
>5

 *(25) BURN DAY 1400 CLOUD COVER, % ? 0 TO 100
>0

 (26) BURN DAY 1400 HAZINESS ? 1-4
        1=VERY CLEAR SKY
        2=AVERAGE CLEAR FOREST ATMOSPHERE
        3=MODERATE FOREST BLUE HAZE
        4=DENSE HAZE
>1

 BURN TIME IS BETWEEN 1200 AND 1600.
 BURN TIME CONDITIONS WILL BE SET TO 1400 CONDITIONS

 (40) EXPOSURE TO WIND ? 1-5
    1 = EXPOSED
    2 = PARTIALLY SHELTERED
    3 = FULLY SHELTERED--OPEN STAND
    4 = FULLY SHELTERED--DENSE STAND
    5 = DIRECT ENTRY OF WIND ADJUSTMENT FACTOR
>1
```

Shade calculations have been adjusted to better account for
1. broad, flat crowns
2. light stocking levels.
In some cases this will result in slightly different moisture predictions and different values of shade, fuel temp, fuel RH. Different predictions can be expected in these situations for versions 3.3 and later:
- timber cover at light stocking levels
- broad, flat crowns
- just before sunset and just after sunrise.

```
(43) MOISTURE INITIALIZATION OPTION ? 1-5 OR QUIT

       1=1-HR FUEL MOISTURE KNOWN FOR BURN DAY -1

       2=COMPLETE WEATHER DATA FOR 3 TO 7 DAYS

       3=INCOMPLETE WEATHER DATA
         RAIN THE WEEK BEFORE THE BURN

       4=INCOMPLETE WEATHER DATA
         NO RAIN THE WEEK BEFORE THE BURN
         WEATHER PATTERN HOLDING
         (NO ADDITIONAL INPUT)

       5=INCOMPLETE WEATHER DATA
         WEATHER PATTERN CHANGING
>4

MOISTURE KEYWORD ?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY HELP,STATUS
>LIST


MOISTURE
 1--RUN OPTION--------------    1=BURN TIME CALCULATIONS
 2--MONTH OF BURN-----------    5.
 3--DAY OF BURN-------------   30.
 4--LATITUDE----------------   40. N
 5--BURN TIME (2400 HOURS)-- 1500.
                              442.=TIME OF SUNRISE
                             1918.=TIME OF SUNSET
 6--FUEL MODEL                  2 = TIMBER (GRASS AND UNDERSTORY)

11--TERRAIN SLOPE, % -------   10.0
12--ELEVATION OF FIRE
     LOCATION, FT ---------- 4500.0
13--ELEVATION OF WEATHER
      OBSERVATIONS, FT------    SAME AS FIRE LOCATION
14--ASPECT------------------    ALL ASPECTS ———— First ranging variable

>

15--CROWN CLOSURE, % -------   10.0
16--FOLIAGE-----------------    PRESENT
17--SHADE TOLERANCE---------    INTOLERANT
18--DOMINANT TREE TYPE------    1=CONIFEROUS
19--AVERAGE TREE HEIGHT, FT    50.0
20--RATIO OF CROWN LENGTH
     TO TREE HEIGHT--------      .7
21--RATIO OF CROWN LENGTH
     TO CROWN DIAMETER-----     3.0
```

```
>

22--BURN DAY 1400 TEMP, F --   60.0  62.0  64.0  66.0  68.0  70.0  72.0
23--BURN DAY 1400 RH, % ----   40.0
24--BURN DAY 1400 20-FOOT
     WIND SPEED, MI/H ------    5.0
25--BURN DAY 1400 CLOUD
     COVER, % -------------      .0
26--BURN DAY 1400 HAZINESS--    1=VERY CLEAR SKY

   ***BURN TIME WEATHER = 1400 WEATHER***
>
40--EXPOSURE OF FUELS TO
      THE WIND--------------    1=EXPOSED
                                 .4=WIND ADJUSTMENT FACTOR
>

43--MOISTURE INITIALIZATION
      CODE------------------    4=INCOMPLETE WEATHER DATA
                                  NO RAIN THE WEEK BEFORE THE BURN
                                  WEATHER PATTERN HOLDING

MOISTURE KEYWORD ?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY HELP,STATUS
>RUN

TABLE VARIABLE ? 0-9

0=NO MORE TABLES            5=FUEL LEVEL RH
1=1-HR FUEL MOISTURE        6=MIDFLAME WINDSPEED
2=DRY BULB TEMPERATURE      7=FUEL LEVEL WINDSPEED
3=AIR RH                    8=SHADE PERCENT
4=FUEL LEVEL TEMPERATURE    9=PROBABILITY OF IGNITION
>1
```

Second ranging variable

We'll refer to this later.

```
==================================================================
1-HR FUEL MOISTURE, %                                       (V4.0)
==================================================================
           I        BURN TIME TEMPERATURE, DEG F
           I
  ASPECT   I     60.     62.     64.     66.     68.     70.     72.
           I-------------------------------------------------------
           I
     N     I     5.1     5.1     5.1     5.0     5.0     5.0     5.0
           I
     NE    I     5.3     5.3     5.2     5.2     5.2     5.2     5.1
           I
     E     I     5.2     5.1     5.1     5.1     5.1     5.0     5.0
           I
     SE    I     5.1     5.1     5.0     5.0     5.0     5.0     5.0
           I
     S     I     4.9     4.9     4.9     4.8     4.8     4.8     4.8
           I
     SW    I     4.8     4.7     4.7     4.7     4.7     4.6     4.6
           I
     W     I     4.8     4.7     4.7     4.7     4.7     4.6     4.6
           I
     NW    I     4.9     4.9     4.9     4.8     4.8     4.8     4.8
>

TABLE VARIABLE ? 0-9

0=NO MORE TABLES              5=FUEL LEVEL RH
1=1-HR FUEL MOISTURE          6=MIDFLAME WINDSPEED
2=DRY BULB TEMPERATURE        7=FUEL LEVEL WINDSPEED
3=AIR RH                      8=SHADE PERCENT
4=FUEL LEVEL TEMPERATURE      9=PROBABILITY OF IGNITION
>0

MOISTURE KEYWORD ?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
      ENGLISH,METRIC,PERCENT,DEGREES,
      COMMENT,KEY HELP,STATUS
>CHANGE

CHANGE WHICH LINE ? 0-59
  (0 MEANS NO MORE CHANGES)
>5

(5) BURN TIME ? 0000-2359
>1800

SINCE YOU HAVE CHANGED BURN TIME, YOU MAY ALSO
WANT TO CHANGE BURN TIME WEATHER
(LINES 35 THROUGH 39)
```

This column assumes a burn time temperature of 60° on each aspect. Note the expected variation in 1-hr moisture depending on aspect.

The moisture is printed to the nearest tenth of a percent to show trends in variation. The nearest percent is close enough for all practical purposes.

Let's try CHANGE for the next run.

```
 CHANGE WHICH LINE ? 0-59
   (0 MEANS NO MORE CHANGES)
>0

 MOISTURE KEYWORD ?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY HELP,STATUS
>LIST


 MOISTURE
  1--RUN OPTION--------------    1=BURN TIME CALCULATIONS
  2--MONTH OF BURN-----------    5.
  3--DAY OF BURN-------------   30.
  4--LATITUDE----------------   40. N
  5--BURN TIME (2400 HOURS)-- 1800.
                               442.=TIME OF SUNRISE
                              1918.=TIME OF SUNSET
  6--FUEL MODEL                  2 = TIMBER (GRASS AND UNDERSTORY)

 11--TERRAIN SLOPE, % -------   10.0
 12--ELEVATION OF FIRE
      LOCATION, FT ---------- 4500.0
 13--ELEVATION OF WEATHER
       OBSERVATIONS, FT------    SAME AS FIRE LOCATION
 14--ASPECT------------------    ALL ASPECTS

>

 15--CROWN CLOSURE, % -------   10.0
 16--FOLIAGE-----------------    PRESENT
 17--SHADE TOLERANCE---------    INTOLERANT
 18--DOMINANT TREE TYPE------    1=CONIFEROUS
 19--AVERAGE TREE HEIGHT, FT    50.0
 20--RATIO OF CROWN LENGTH
      TO TREE HEIGHT--------      .7
 21--RATIO OF CROWN LENGTH
      TO CROWN DIAMETER-----     3.0

>

 22--BURN DAY 1400 TEMP, F --   60.0  62.0  64.0  66.0  68.0  70.0  72.0
 23--BURN DAY 1400 RH, % ----   40.0
 24--BURN DAY 1400 20-FOOT
      WIND SPEED, MI/H ------    5.0
 25--BURN DAY 1400 CLOUD
      COVER, % -------------      .0
 26--BURN DAY 1400 HAZINESS--    1=VERY CLEAR SKY
```

```
 35--BURN TIME TEMPERATURE, F   60.0  62.0  64.0  66.0  68.0  70.0  72.0
 36--BURN TIME RH, % --------   40.0
 37--BURN TIME 20-FOOT
      WIND SPEED, MI/H ------    5.0
 38--BURN TIME CLOUD COVER, %     .0
 40--EXPOSURE OF FUELS TO
       THE WIND--------------    1=EXPOSED
                                  .4=WIND ADJUSTMENT FACTOR
>

 43--MOISTURE INITIALIZATION
       CODE------------------    4=INCOMPLETE WEATHER DATA
                                   NO RAIN THE WEEK BEFORE THE BURN
                                   WEATHER PATTERN HOLDING
```

See the listing from the previous run. These values were reset because of burn time choice. Be careful when using CHANGE to set up for the next run. Always check your listing to see if it's what you intended. (Now there are 3 ranging variables.)

```
 MOISTURE KEYWORD ?
 ENTER INPUT,LIST,CHANGE,RUN,QUIT,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY HELP,STATUS
QUIT


 FINISH MOISTURE -- BACK TO FIRE2



 FIRE2 KEYWORD ?
 ENTER IGNITE,MOISTURE,RH,CUSTOM,
       TERSE,WORDY,PAUSE,NOPAUSE,LOG,NOLOG,
       ENGLISH,METRIC,PERCENT,DEGREES,
       COMMENT,KEY,HELP,STATUS,QUIT
QUIT


 DO YOU  R E A L L Y  WANT TO TERMINATE THIS RUN ?  Y-N
Y

 PART OF THIS RUN MAY HAVE BEEN LOGGED.
 THE FILE NAME IS:  LOGFIL
 PRINT THE FILE NOW AND DELETE IT.


 FIRE2 RUN TERMINATED.
 ******************************
```

APPENDIX B: INPUT/OUTPUT REFERENCE SHEETS

This appendix includes input/output reference sheets for all modules of the FIRE1 and FIRE2 programs of BEHAVE. Some have the same items and line numbers as those given in Part 1 of this manual (DIRECT, SIZE, CONTAIN, DISPATCH), some are revised to reflect the changes described in the body of this paper (SPOT, SITE), and others are for new modules (SCORCH, MORTALITY, MAP, SLOPE, MOISTURE, IGNITE, RH). To avoid confusion with previous versions, a date is given at the bottom of each sheet.

The information on each sheet includes the item name, line number (as used by the CHANGE command), an * to indicate that a range of values is allowed, English and metric units, and comments. Only one blank is given for each input and output value. These are reference sheets rather than worksheets. A person will normally use a computer printout as a record of a run rather than writing the results on a worksheet. This is especially the case when a range of values is entered for two input values and the resulting output is a series of 7 x 7 tables.

These input/output sheets are alphabetized by module name. Refer to figure 3 for the relationship among the modules.

CONTAIN Module Input/Output
(FIRE1 program)

		UNITS English	UNITS Metric		COMMENTS
INPUT					
1	Mode of attack 1 = Head 2 = Rear			____	Direct attack
2	Run option 1 = Compute line building rate 2 = Compute burned area			____	
*3	Forward rate of spread	ch/h	m/min	____	May come from SIZE linked to DIRECT
*4	Initial fire size	ac	ha	____	
*5	Length-to-width ratio			____	
*6	Burned area target	ac	ha	____	If line building rate is computed
*7	Total line building rate	ch/h	m/min	____	If burned area is computed Total line building rate is twice the rate per flank
OUTPUT					
1	Total length of line	ch	m	____	Perimeter of burned area
2	Total containment time	h	h	____	
3	Total line building rate	ch/h	m/min	____	
or					
3	Final fire size	ac	ha	____	

*A range of inputs is allowed

DIRECT Module Input/Output
(FIRE1 program)

		UNITS English	UNITS Metric		COMMENTS
INPUT					
1	Fuel model			____	Enter 0 for two-fuel-model concept input
*2	1-h fuel moisture	%	%	____	
*3	10-h fuel moisture	%	%	____	If the fuel model has this size class
*4	100-h fuel moisture	%	%	____	If the fuel model has this size class
*5	Live herbaceous fuel moisture	%	%	____	If the fuel model has this size class
*6	Live woody fuel moisture	%	%	____	If the fuel model has this size class
*7	Midflame windspeed	mi/h	km/h	____	
*8	Slope	% or deg	% or deg	____	Units set using keywords PERCENT and DEGREES
*9	Direction of wind vector, deg clockwise from uphill	deg	deg	____	If windspeed is not zero. Direction that the wind is pushing the fire
*10	Direction for spread calculations, deg clockwise from uphill (or from the wind vector if slope is zero)	deg	deg	____	Direction of maximum spread can be calculated
OUTPUT					
1	Rate of spread	ch/h	m/min	____	Fire behavior in the direction specified in input line 10
2	Heat per unit area	Btu/ft^2	kJ/m^2	____	
3	Fireline intensity	Btu/ft/s	kW/m	____	
4	Flame length	ft	m	____	
5	Reaction intensity	Btu/ft^2/min	kW/m^2	____	
6	Effective windspeed	mi/h	km/h	____	
7	Direction of maximum spread, deg clockwise from uphill	deg	deg	____	

*A range of inputs is allowed

DISPATCH Module Input/Output (FIRE1 program)

	UNITS English	UNITS Metric		COMMENTS
INPUT				
1 Fuel model			____	
2 Dead fuel moisture	%	%	____	1-h, 10-h, and 100-h
3 Live fuel moisture	%	%	____	Woody and herbaceous
4 20-foot windspeed	mi/h	km/h	____	Upslope wind
5 Wind adjustment factor			____	Midflame wind is 20-ft wind times wind adj. factor
6 Slope	% or deg	% or deg	____	
7 Elapsed time from ignition to attack	h	h	____	
8 Total line building rate	ch/h	m/min	____	Twice the rate per flank
OUTPUT				
Forward rate of spread	ch/h	m/min	____	
Heat per unit area	Btu/ft^2	kJ/m^2	____	
Fireline intensity	Btu/ft/s	kW/m	____	
Flame length	ft	m	____	
Perimeter at time of attack	ch	m	____	
Area at time of attack	ac	ha	____	
Head attack:				
Elapsed time from attack to containment	h	h	____	
Total length of line	ch	m	____	Perimeter of burned area
Final fire size	ac	ha	____	
Rear attack:				
Elapsed time from attack to containment	h	h	____	
Total length of line	ch	m	____	Perimeter of burned area
Final fire size	ac	ha	____	

IGNITE Module Input/Output
(FIRE2 program)

		UNITS English	UNITS Metric		COMMENTS
INPUT					
*1	Dry bulb temperature	°F	°C	____	
*2	1-h fuel moisture	%	%	____	
*3	Shade	%	%	____	
OUTPUT					
	Probability of ignition	%	%	____	

*A range of values is allowed.

MAP Module Input/Output
(FIRE1 program)

		UNITS English	UNITS Metric		COMMENTS
INPUT					
1	Map scale	rep frac or in/mi	rep frac or cm/km	____	
2	Units option 1 = spread distance 2 = spot distance 3 = rate of spread			____	
*3	Spread distance	ch	m	____	If units option = 1
*4	Maximum spotting distance	mi	km	____	If units option = 2
*5	Rate of spread	ch/h	m/min	____	If units option = 3
*6	Elapsed time	h	h	____	If units option = 3
OUTPUT					
	Map spread distance	in	cm	____	If units option = 1, 3
or	Map maximum spotting distance	in	cm	____	If units option = 2
					In the direction of the wind

*A range of values is allowed

MOISTURE Module Output
(FIRE2 program)

(Use input sheets for SITE and MOISTURE combined)

		UNITS English	UNITS Metric		COMMENTS
1	1-h fuel moisture	%	%	____	
2	Dry bulb temperature	°F	°C	____	
3	Air RH	%	%	____	
4	Fuel level temperature	°F	°C	____	
5	Fuel level RH	%	%	____	
6	Midflame windspeed	mi/h	km/h	____	
7	Fuel level windspeed	mi/h	km/h	____	
8	Shade	%	%	____	
9	Probability of ignition	%	%	____	

MORTALITY Module Input/Output
(FIRE1 program)

	UNITS English	UNITS Metric		COMMENTS
INPUT				
*1 Scorch height	ft	m	_____	May come from SCORCH
*2 Tree height	ft	m	_____	
*3 Crown ratio			_____	Ratio of crown length to tree height
*4 Bark thickness	in	cm	_____	
Direct input or from:				
Species 1 = western larch, Douglas-fir 2 = western hemlock 3 = Engelmann spruce, western red cedar 4 = lodgepole pine, subalpine fir			_____	
DBH	in	cm	_____	
OUTPUT				
1 Mortality level	%	%	_____	
2 Crown volume scorch	%	%	_____	

* Range of values is allowed.

RH Module Input/Output
(FIRE2 program)

	UNITS		COMMENTS
	English	*Metric*	
INPUT			
*1 Dry bulb temperature	°F	°C	———
*2 Wet bulb temperature	°F	°C	———
*3 Elevation	ft	m	———
OUTPUT			
1 Relative humidity	%	%	———
2 Dew point	°F	°C	———

* A range of values is allowed.

SCORCH Module Input/Output
(FIRE1 program)

	UNITS English	UNITS Metric		COMMENTS
INPUT				
*1 Ambient air temperature	°F	°C	——	
*2 Flame length	ft	m	——	May come from DIRECT
*3 Midflame windspeed	mi/h	km/h	——	May come from DIRECT
OUTPUT				
Crown scorch height	ft	m	——	

* A range of values is allowed.

SITE and **MOISTURE** Module Input
(SITE in FIRE1 program; MOISTURE in FIRE2 program)

		UNITS English	UNITS Metric		COMMENTS
INPUT					
1	MOISTURE run option 1 = Burn time calculations 2 = Hourly calculations (graphic output)			___	MOISTURE only
TIME AND LOCATION					
2	Month of burn			___	
3	Day of burn			___	
4	Latitude	deg	deg	___	
	State			___	SITE only If latitude is not known
5	Burn time (2400 hour)			___	
FUEL MODEL					
6	Fuel model			___	
FUEL MOISTURE					
7	10-h fuel moisture	%	%	___	SITE only If this size class is in the fuel model
8	100-h fuel moisture	%	%	___	
9	Live herbaceous moisture	%	%	___	
10	Live woody moisture	%	%	___	
SLOPE, ELEVATION, ASPECT					
*11	Slope	% or deg	% or deg	___	Units set using keywords PERCENT or DEGREES
	Map scale	rep frac or in/mi	rep frac or cm/km	___	SITE only If slope is not known
	Contour interval	ft	m	___	
	Map distance	in	cm	___	
	Number of contour intervals			___	
*12	Elevation of fire location	ft	m	___	

* A range of values is allowed in MOISTURE only, run option 1.

SITE and MOISTURE Module Input, continued:

	UNITS English	UNITS Metric		COMMENTS
SLOPE, ELEVATION, ASPECT				
13 Elevation of T/RH obs.	ft	m	____	
*14 Aspect (N,NE,E,SE,S, SW,W,NW)			____	If slope is not zero
TIMBER OVERSTORY DESCRIPTION				
*15 Crown closure	%	%	____	
16 Foliage present or absent			____	If crown closure is not zero
17 Shade tolerant or intolerant			____	If crown closure is not zero
18 Dominant tree type 1 = Coniferous 2 = Deciduous			____	If crown closure is not zero
*19 Average tree height	ft	m	____	If crown closure is not zero
*20 Ratio of crown length to tree height			____	If crown closure is not zero
*21 Ratio of crown length to crown diameter			____	If crown closure is not zero
EARLY AFTERNOON WEATHER				
*22 Burn day 1400 temperature	°F	°C	____	Required input. If burn time is between 1200 and 1600, 1400 weather is used for burn time weather.
*23 Burn day 1400 relative humidity	%	%	____	Required input. If burn time is between 1200 and 1600, 1400 weather is used for burn time weather.
*24 Burn day 1400 20-ft windspeed	mi/h	km/h	____	Required input. If burn time is between 1200 and 1600, 1400 weather is used for burn time weather.
*25 Burn day 1400 cloud cover	%	%	____	Required input. If burn time is between 1200 and 1600, 1400 weather is used for burn time weather.
26 Burn day 1400 haziness 1 = very clear sky 2 = average clear forest atmosphere 3 = moderate forest blue haze 4 = dense haze or light to moderate smoke			____	Required input. If burn time is between 1200 and 1600, 1400 weather is used for burn time weather.

* A range of values is allowed in MOISTURE only, run option 1.

SITE and **MOISTURE** Module Input, continued:

		UNITS English	UNITS Metric		COMMENTS
SUNSET WEATHER					
*27	Sunset temperature	°F	°C	____	For burn time after sunset and before 1200 12 16 SS SR 12
*28	Sunset relative humidity	%	%	____	
*29	Sunset 20-ft windspeed	mi/h	km/h	____	
*30	Sunset cloud cover	%	%	____	
SUNRISE WEATHER					
*31	Sunrise temperature	°F	°C	____	For burn time after sunrise and before 1200 12 16 SS SR 12
*32	Sunrise relative humidity	%	%	____	
*33	Sunrise 20-ft windspeed	mi/h	km/h	____	
*34	Sunrise cloud cover	%	%	____	
BURN TIME WEATHER					
*35	Burn time temperature	°F	°C	____	For burn time after 1600 or before 1200 12 16 SS SR 12
*36	Burn time relative humidity	%	%	____	
*37	Burn time 20-ft windspeed	mi/h	km/h	____	
*38	Burn time cloud cover	%	%	____	For burn time (after 1600 & before SS) or (after SR and before 1200) 12 16 SS SR 12
39	Burn time haziness 1 = very clear sky 2 = average clear forest atmosphere 3 = moderate forest blue haze 4 = dense haze or light to moderate smoke			____	For burn time after sunrise and before 1200 12 16 SS SR 12
BURN TIME WIND					
40	Exposure of fuels to the wind 0 = Don't know (SITE only) 1 = Exposed 2 = Partially sheltered 3 = Fully sheltered—open stand 4 = Fully sheltered—closed stand 5 = Direct entry of wind adjustment factor			____	

* A range of values is allowed in MOISTURE only, run option 1.

SITE and MOISTURE Module Input, continued:

	UNITS English	UNITS Metric		COMMENTS
BURN TIME WIND				
41 Burn time direction of wind vector, degrees clockwise from uphill			____	SITE only
42 Direction for spread calculations, degrees clockwise from uphill or from wind vector if slope = 0 (direction of maximum spread can be calculated)			____	SITE only
MOISTURE INITIALIZATION OPTION				
43 Moisture initialization option 1 = Fine fuel moisture known the day before the burn 2 = Complete weather available for 3 to 7 days prior to the burn 3 = Incomplete weather data and it rained the week before the burn 4 = Incomplete weather data, no rain the week before the burn, and weather pattern is stable (no additional input) 5 = Incomplete weather data; weather pattern changing			____	
FINE FUEL MOISTURE KNOWN FOR THE DAY BEFORE THE BURN				
*44 Burn day -1 fine fuel moisture	%	%	____	For moisture initialization option 1

COMPLETE WEATHER AVAILABLE FOR 3 TO 7 DAYS PRIOR TO THE BURN

45 Number of days of weather ____

	-1	-2	-3	-4	-5	-6	-7	
46 Burn day -x 1400 temperature, °F or °C	____	____	____	____	____	____	____	For moisture initialization option 2
47 Burn day -x 1400 relative humidity, %	____	____	____	____	____	____	____	
48 Burn day -x 1400 20-ft windspeed, mi/h or km/h	____	____	____	____	____	____	____	
49 Burn day -x 1400 cloud cover, %	____	____	____	____	____	____	____	
50 Burn day -x rain amount, hundredths of an inch or cm	____	____	____	____	____	____	____	

* A range of values is allowed in MOISTURE only, run option 1.

SITE and **MOISTURE** Module Input, continued:

	UNITS			COMMENTS
	English	*Metric*		
INCOMPLETE WEATHER DATA; RAIN THE WEEK BEFORE THE BURN				
*51 Number of days before the burn that rain occurred			___	For moisture initialization option 3
*52 Rain amount	hundredths of an inch	cm	___	
*53 1400 temperature on the day it rained	°F	°C	___	
54 Sky condition from the day it rained until burn day 1 = clear 2 = cloudy 3 = partly cloudy			___	
INCOMPLETE WEATHER DATA; NO RAIN THE WEEK BEFORE THE BURN; WEATHER PATTERN HOLDING				
No additional input				For moisture initialization option 4
INCOMPLETE WEATHER DATA; WEATHER PATTERN CHANGING				
*55 Burn day -1 1400 temperature	°F	°C	___	For moisture initialization option 5
*56 Burn day -1 1400 relative humidity	%	%	___	
*57 Burn day -1 1400 20-ft windspeed	mi/h	km/h	___	
*58 Burn day -1 1400 cloud cover	%	%	___	
59 Weather condition prior to burn day -1 1 = hot and dry 2 = cool and wet 3 = between 1 and 2			___	

*A range of values is allowed in MOISTURE only, run option 1.

SITE Module Output
(FIRE1 program)

	UNITS English	UNITS Metric		COMMENTS
INTERMEDIATE VALUES				
Time of sunset			____	
Time of sunrise			____	
Wind adjustment factor			____	
Fuel surface temperature	°F	°C	____	
Fuel level relative humidity	%	%	____	
Percent shade	%	%	____	
Fine dead fuel moisture	%	%	____	
BASIC INPUT				
Fuel model			____	Corresponds to DIRECT input and output
1-h fuel moisture	%	%	____	
10-h fuel moisture	%	%	____	
100-h fuel moisture	%	%	____	
Live herbaceous fuel moisture	%	%	____	
Live woody fuel moisture	%	%	____	
Midflame windspeed	mi/h	km/h	____	
Slope	%	%	____	
Direction of wind vector, degrees clockwise from uphill (or from the wind vector if slope is zero)	deg	deg	____	
Direction for spread calculations, degrees clockwise from uphill (or from the wind vector if slope is zero)	deg	deg	____	

SITE Module Output , continued:

	UNITS			COMMENTS
	English	*Metric*		
OUTPUT				
Rate of spread	ch/h	m/min	____	
Heat per unit area	Btu/ft^2	kJ/m^2	____	
Fireline intensity	Btu/ft/s	kW/m	____	
Flame length	ft	m	____	
Reaction intensity	$Btu/ft^2/min$	kW/m^2	____	
Effective windspeed	mi/h	km/h	____	
Direction of maximum spread, degrees clockwise from uphill	deg	deg	____	

MOISTURE Module Output
(FIRE2 program)

		UNITS			COMMENTS
		English	*Metric*		
1	1-h fuel moisture	%	%	____	
2	Dry bulb temperature	°F	°C	____	
3	Air RH	%	%	____	
4	Fuel level temperature	°F	°C	____	
5	Fuel level RH	%	%	____	
6	Midflame windspeed	mi/h	km/h	____	
7	Fuel level windspeed	mi/h	km/h	____	
8	Shade	%	%	____	
9	Probability of ignition	%	%	____	

SIZE Module Input/Output
(FIRE1 program)

		UNITS English	UNITS Metric		COMMENTS
INPUT					
*1	Rate of spread	ch/h	m/min	____	May come from DIRECT
*2	Effective windspeed	mi/h	km/h	____	May come from DIRECT
*3	Elapsed time	h	h	____	
OUTPUT					
1	Area	ac	ha	____	
2	Perimeter	ch	m	____	
3	Length-to-width ratio			____	
4	Forward spread distance	ch	m	____	
5	Backing spread distance	ch	m	____	
6	Maximum width of fire	ch	m	____	

*A range of values is allowed.

SLOPE Module Input/Output
(FIRE1 program)

	UNITS			COMMENTS
	English	*Metric*		
INPUT				
1 Map scale	rep frac or in/mi	rep frac or cm/km	____	Can enter map scale either way
*2 Contour interval	ft	m	____	
*3 Map distance	in	cm	____	
*4 Number of contour intervals			____	
OUTPUT				
1 Slope	% or deg	% or deg	____	Units set using keywords PERCENT or DEGREES
2 Elevation change	ft	m	____	
3 Horizontal distance	ft	m	____	

* A range of values is allowed.

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SPOT Module Input/Output
(FIRE1 program)

		UNITS English	UNITS Metric		COMMENTS
INPUT					
1	Firebrand source 1 = torching trees 2 = burning pile 3 = wind-driven surface fire			____	
*2	Mean cover height	ft	m	____	For torching trees or burning pile
*3	20-ft windspeed	mi/h	km/h	____	May come from DIRECT for wind-driven surface fire
*4	Ridge-to-valley elevation difference	ft	m	____	
*5	Ridge-to-valley horizontal distance	mi	km	____	If ridge-to-valley elevation difference is not equal to zero
6	Spotting source location 0 = midslope, windward side 1 = valley bottom 2 = midslope, leeward side 3 = ridgetop			____	
7	Tree species 1 = Engelmann spruce 2 = Douglas-fir, subalpine fir 3 = hemlock 4 = ponderosa pine, lodgepole pine 5 = white pine 6 = balsam fir, grand fir 7 = slash pine, longleaf pine 8 = pond pine, shortleaf pine 9 = loblolly pine			____	For torching trees
*8	Torching tree DBH	in	cm	____	
*9	Torching tree height	ft	m	____	
*10	Number of trees torching together			____	
*11	Continuous flame height	ft	m	____	For burning pile
*12	Flame length	ft	m	____	For wind-driven surface fire May come from DIRECT
OUTPUT					
	Maximum spot fire distance	mi	km	____	

*A range of values is allowed.

Andrews, Patricia L.; Chase, Carolyn H. 1989. BEHAVE: fire behavior prediction and fuel modeling system—BURN subsystem, Part 2. Gen. Tech. Rep. INT-260. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 93 p.

This is the third publication describing the BEHAVE system of computer programs for predicting behavior of wildland fires. This publication adds the following predictive capabilities: distance firebrands are lofted ahead of a wind-driven surface fire, probabilities of firebrands igniting spot fires, scorch height of trees, and percentage of tree mortality. The system includes a separate module for graphing moisture content of fine, dead fuels. Basic assumptions, limitations, and application of the prediction models are discussed. Previous publications in the BEHAVE series are BEHAVE: fire behavior prediction and fuel modeling system—FUEL subsystem (Burgan and Rothermel 1984), and BEHAVE: fire behavior prediction and fuel modeling system—BURN subsystem, Part 1 (Andrews 1986).

KEYWORDS: wildland fire, fire management, fire effects, firebrand, fire ignition, tree mortality

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

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White Pine Blister Rust in Northern Idaho and Western Montana: Alternatives for Integrated Management

**Susan K. Hagle
Geral I. McDonald
Eugene A. Norby**

THE AUTHORS

SUSAN K. HAGLE is plant pathologist for Cooperative Forestry and Pest Management, Northern Region, Forest Service, U.S. Department of Agriculture, Missoula, MT.

GERAL I. MCDONALD is plant pathologist for the Intermountain Research Station, Moscow, ID.

EUGENE A. NORBY (retired), was forest silviculturist for the Clearwater National Forest, Northern Region, Orofino, ID.

PREFACE

Western white pine management has undergone dramatic change since the introduction of white pine blister rust. This report summarizes major events and presents current technology for foresters managing stands in the western white pine type of Idaho and Montana. Site-specific management alternatives are developed through the use of a dichotomous key. Supporting information is provided in a series of subject appendixes. We discuss the concept of Rust Hazard and its application to stand management. Approaches to using rust resistance and intermediate stand treatments are explained. Regardless of stand management intensity, this information should provide insight into both the influence of white pine blister rust on stands and the effects of stand and site manipulation on the disease.

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Intermountain Research Station
324 25th Street
Ogden, UT 84401

White Pine Blister Rust in Northern Idaho and Western Montana: Alternatives for Integrated Management

Susan K. Hagle
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INTRODUCTION

Western white pine (*Pinus monticola* Dougl. ex D. Don.) was once the most sought after conifer species in the Western United States, particularly in Idaho and western Montana (Davis 1942). The major impetus for settlement of the Clearwater region of Idaho was provided by the valuable white pine forests. Many past and present forest products companies in Idaho and Montana owe their beginnings to white pine. The lumber is soft, white, and easily worked, making it useful for a wide variety of wood products. Silvical characteristics that add to its popularity are its fast growth rate, good form, and potentially greater optimum stocking density than associated conifers (Watt 1960). To this day, stumpage values tend to be higher for western white pine than associated conifers (Manning and Howe 1983). With the exception of white pine blister rust, white pine is less susceptible to damage by insects and diseases than are other conifers.

Unfortunately, management of western white pine has been confounded by the introduction of the fungal disease white pine blister rust, caused by *Cronartium ribicola* Fisch. This disease was introduced into Western North America from Europe in 1910 on infected eastern white pine seedlings grown in France and planted near Vancouver, BC. Western white pine proved to be highly susceptible to blister rust, with mortality rates of 90 percent or more in what were once vigorous, well-stocked stands.

History of Control Efforts

White pine blister rust requires an alternate host, currant or gooseberry (*Ribes* spp.), to complete its life cycle.

Ribes are associated with western white pine throughout its range. Early attempts to halt spread of the disease were aimed at breaking the disease cycle by eradicating the alternate host from within and around valuable white pine stands. This approach had been successful in reducing infection in the Lake States (King and others 1960). Eradication work began in the Northern Region in 1924 and continued until 1966.

In 1966 and 1967, the Northern Region of the Forest Service, U.S. Department of Agriculture, conducted surveys to evaluate the effectiveness of *Ribes* population reduction in controlling pine infection (Carlson and Toko 1968). Results demonstrated that *Ribes* density could not be sufficiently lowered by pulling or spraying plants. In many cases, *Ribes* populations were reduced from thousands per acre to as few as several bushes per acre after numerous treatments. Nevertheless, when only a few bushes remained proportions of pines infected in the stands were not significantly reduced. These findings are consistent with experience in the Lake States. King (1958) reported that "study results indicate that beyond relatively few bushes per acre, *Ribes* population has little effect on fatal blister rust infection." The conclusion was that *Ribes* eradication was not economically feasible in the Northern Rocky Mountains (Ketcham and others 1968).

From about 1957 until 1966, attempts also were made to control the disease by treating infected stands with antibiotics. It was hoped that this type of treatment might eliminate existing infections and immunize the trees against further infection, at least for a period of time (Moss and others 1960). Antibiotics were difficult and expensive to apply, and results were erratic (Dimond 1966). As a result, this type of control effort also was largely discontinued after 1966.

Forest Service stand management policy regarding western white pine included three major changes as of 1966 (Ketcham and others 1968): (1) planting of western white pine was discontinued on an operational basis, (2) thinning and weeding would favor species other than western white pine, and (3) salvage of merchantable western white pine damaged by blister rust or bark beetles was accelerated. This was in conjunction with the cessation of *Ribes* eradication efforts and curtailment of antibiotic use for direct blister rust control. White pine was being temporarily abandoned in timber management. Time was needed to develop rust-resistant pine, a program that was under way and appeared promising.

Disease Resistance

As early as 1933, pathologists noticed that even in the most heavily infected stands, a few individual white pines could be found that were free of the rust and apparently resistant to the disease. It was not until 1949 that research was initiated to determine if genetic resistance did

in fact exist in western white pine (Bingham and others 1953). The results of these early experiments demonstrated that resistance to blister rust does exist in natural stands and that this resistance can be passed on to progeny under controlled conditions. As a result, the cooperative resistance breeding program became operational in USDA Forest Service, Intermountain Station and Northern Region in 1957 (Bingham and others 1973).

It was nearly 15 years before seed was operationally available from this first generation of selectively bred rust-resistant trees (F_1). Seedlings from the second generation (F_2) are now being outplanted. Demand for the seed is increasing. Seedlings of these seed sources placed in test plantations are surviving even better than predicted (Bingham and others 1973).

Unfortunately, genetic resistance to blister rust is not infallible because the fungus may genetically overcome host resistance (Kinloch 1982). Strains of *C. ribicola* capable of overcoming resistance in the pine host have been discovered recently in Oregon (McDonald and others 1984) and Japan (Yokota 1983).

Integrated Management

The alternatives presented here are based on four major goals for western white pine management: (1) reduce probability of pine infection, (2) reduce pine mortality following infection, (3) maintain genetic diversity of white pine for silvical characteristics in addition to rust resistance, and (4) minimize selection pressure on the rust.

Pine infection can be reduced through use of rust-resistant pine and by minimizing *Ribes* populations. Mortality of infected pine can be reduced through intermediate treatment such as pruning and canker excision. Genetic diversity of white pine can be maintained through an aggressive program of selection and testing of new candidate rust-resistant trees and through judicious use of lower levels of rust resistance. Selection pressure on the fungus can be minimized by conservative use of highly rust-resistant pine stock.

The rust and its hosts maintain an intimate and dynamic genetic association. Experience from agricultural crops such as wheat and wheat rust diseases has shown that a limited host gene pool results in natural selection for rust genotypes that allow the fungi to overcome host resistance. Precautions against undue selection pressure on the rust are only prudent. Genetic diversity and economical production of western white pine timber can be obtained through matching levels of resistance with levels of rust hazard. Rust hazard is defined as "the favorableness of the particular site for the development of the rust" (Stillinger 1943).

Intermediate stand treatments, such as pruning, can further enhance genetic diversity because lower levels of host resistance can be successful on sites with higher rust hazard through these intensive management procedures (Brown 1972; Hunt 1982; Nicholls and Anderson 1977; Weber 1964). Advanced natural regeneration and numerous plantations of nonselected (for blister rust resistance) stock are now of an age at which intermediate treatments will make the difference between bringing a considerable portion of the white pine through to a commercial product or starting over.

The factors to be considered in managing western white pine as a stand component can be confusing, causing significant options or influences to be overlooked. This report identifies some of these options and influences to aid in developing comprehensive site-specific management plans.

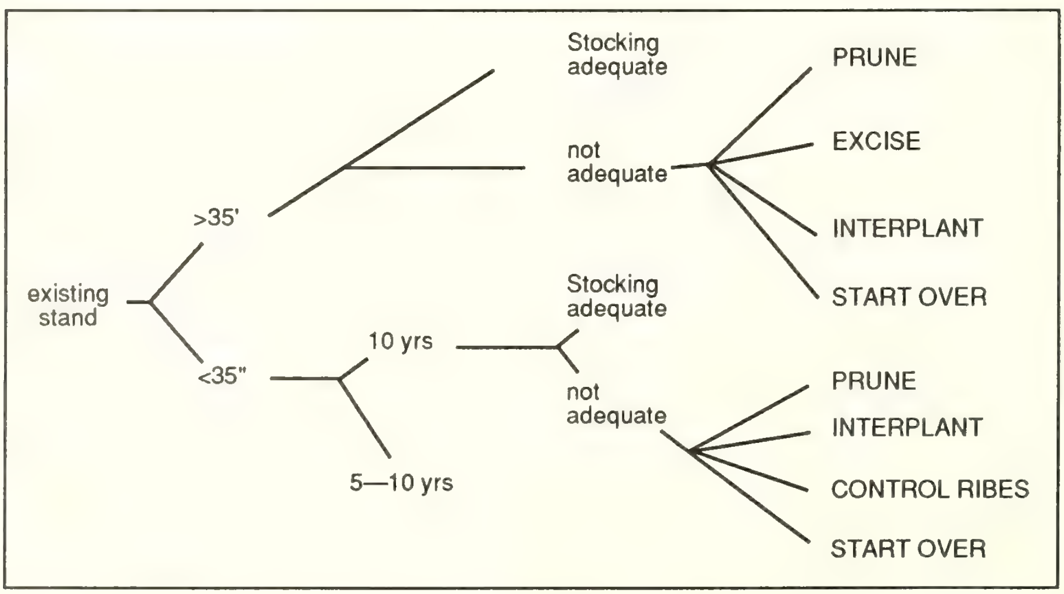

Figure 1—Decision key for managing existing stands.

MANAGEMENT ALTERNATIVES

Our intention is not to prescribe treatments, but rather to stimulate thought and to provide further information to aid in decision making. Alternatives are presented that relate to specific stand or site characteristics. Managers must decide which alternatives are operationally and economically viable for their own situation. We have tried to summarize the voluminous information regarding management of white pine in the presence of blister rust into a format that simplifies interpretation.

Alternatives are presented in a dichotomous key format, beginning with general information. The first pair in this key appears as:

1. Sites to be regenerated...
   1'. Existing stands to be managed...

If the stand fits the latter, a series of questions will attempt to typify the stand to lead to a set of alternatives for that stand. The next major division is based on average stand height (fig. 1). If the stand is taller than 35 feet, only existing infections are likely to result in mortality. Stands that average less than 35 feet in height are subject to death due to both existing and future infections.

In setting height limits for stand separation, the assumption is that white pine will seldom be found as a significantly all-aged stand due to requirements for seedbed and sunlight.

The first alternatives considered try to obtain adequate stocking with existing stands. Destruction of the stand or interplanting among acceptable crop trees, creating an uneven-aged stand, are considered to be "last ditch" efforts when the existing stand cannot be treated economically to retain adequate stocking.

Specific information on how rust hazard is measured, how rust status data are taken, characteristics of genetically improved stock, how to thin and prune, and other related information is presented in appendixes. Appendixes that pertain specifically to items in the decision key are noted in parentheses.

If the site is to be regenerated but has not yet been cut, options that may lessen rust hazard are suggested. For example, a shelterwood method of regeneration may be considered with the goal of reducing viability of *Ribes* seed stored on the site.

The other major section of the key deals with use of blister rust-resistant white pine to regenerate sites. Based on the rust hazard, white pine seedlings of a variety of genetic derivations are considered for regeneration. White pine seedling types, ranging from wild, natural regeneration to rust-resistant planting stock, are matched to five levels of rust hazard (fig. 2).

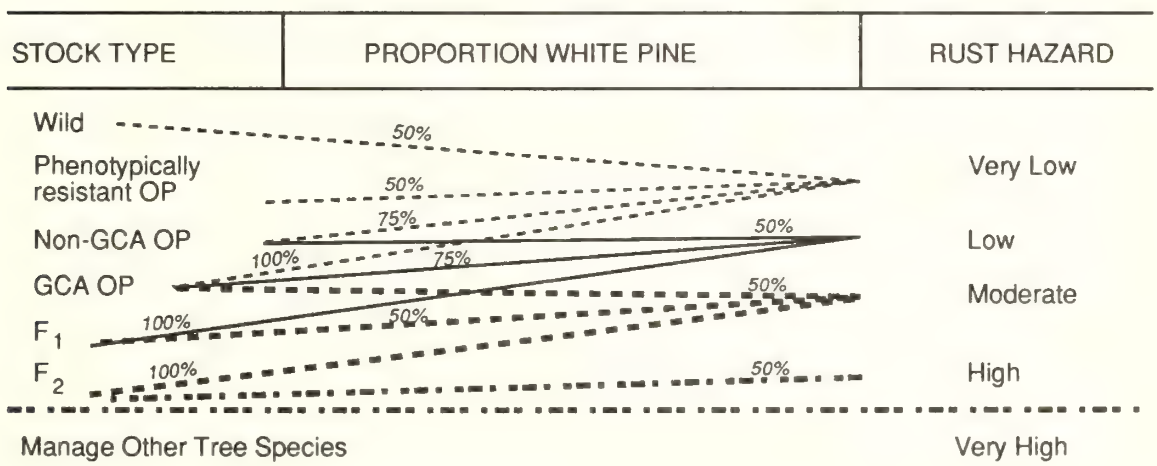

Figure 2—Key for matching western white pine stock types to rust hazard. Percentages are recommended western white pine component of stands. OP = open pollinated; GCA = general combining ability; F_1 = GCA x GCA; F_2 = F_1 x F_1. refer to appendix F for further explanation of stock type. Refer to appendix B for explanation of rust hazard.

Planting stock recommendations also are based on the relative proportions of white pine to be planted in stands. Greater white pine components result in higher risk of loss to blister rust. Therefore, stock types with higher levels of resistance are recommended as white pine proportions are increased. Economic advantages of managing for higher proportions of white pine in stands may justify the greater risk on some sites as demonstrated by Manning and Howe (1983). They reported an economic analysis of reforesting with blister rust-resistant white pine in combinations with other commercial conifer species. Using existing stands on the Wallace Ranger District, Idaho Panhandle National Forests, as a basis, they compared projected stands reforested with planted F_1, F_2, and wild, natural western white pine. A Stand Prognosis Model developed by Wykoff and others (1982) was used to simulate development of fictitious and existing sapling stands to culmination of mean annual increment.

Results of this analysis indicated that increasing the proportion of white pine on north-facing slopes from 39 percent (with wild stock) to 68 percent (with F_2 stock) could increase discounted revenues from $265.86/acre to $1,106.23/acre. Douglas-fir, grand fir, and western hemlock were the other primary components of the stands on north-facing slopes. Greater white pine components were also economically advantageous in simulated stands on south-facing slopes but less so than on north-facing slopes.

Discounted revenue increases for stands with larger white pine components were attributed to increased yield because of faster growth, better form, and higher stumpage prices of white pine compared with other species. On south slopes, however, ponderosa pine is nearly as good as western white pine in growth, form, and stumpage prices.

Height growth of western white pine is better than that of Douglas-fir in 30-year-old stands on sites with white pine site index 80, while the inverse is true for site index 40 (Deitschman and Green 1965). Planting purely white pine should only be considered for sites with especially high white pine growth indices (appendix A) and very low to moderate rust hazard (appendix B). Managing for pure stands of any species also may be subject to agency policy. Therefore, stock type recommendations in the decision key are presented for (1) mixed species stands and (2) pure western white pine stands.

COMPUTER PROGRAMS

Computer programs are available that calculate the rust index and 40-year mortality predictions based on rust status. They are housed at the USDA Forest Service National Computer Center in Fort Collins, CO.

Data entry is simplified by a program that queries the user for the correct input. The program constructs a header card containing pertinent information such as user name, agency, location, stand designation and location, and so forth. The user is then asked whether the rust index program or rust status program is to be run. The next series of questions will construct the appropriate array for the rust index (table 1) or rust status (appendix D) using the data input.

Assistance in obtaining access and directions for utilizing the programs is available for Federal agencies through USDA Forest Service, Northern Region, Cooperative Forestry and Pest Management. For State and private agencies in Washington, Idaho, and Montana, assistance is obtained through the State Department of Lands, Forestry Division, pest management specialists. Copies of programs with brief explanation of construction are available also from these sources.

Table 1—Rust hazard estimation from rust index values

Index value	Rust hazard level[1]
<0.00005	1 very low
0.00005-0.00499	2 low
0.00500-0.09999	3 moderate
0.1000-1.00000	4 high
>1.00000	5 very high

[1]Hazard levels apply only to wild-type white pines.

KEY TO ALTERNATIVES

1 Sites to be regenerated 30

Refers to sites with mature stands that will be removed for regeneration, and sites where stands have already been removed but still need regeneration.

1' Existing stands to be managed 2

Generally refers to immature stands that may receive intermediate treatments, although in some cases mature stands also may be treated where stand removal is not the goal.

2(1') White pine is an important component (A) 4

This decision is left to the manager. Species composition, value of western white pine present, and condition of alternative species in the stand are important considerations. Treatment of white pine is unlikely to be economical if it is not an important component in the stand.

2'(1') White pine is not an important component 3

3(2') Site is suitable for white pine (A), consider managing to reduce *Ribes* populations (G) .... End

If white pine is not presently an important component, but the site is suited for growing white pine, efforts could be made to avoid increasing or to reduce *Ribes* populations so that the rust hazard does not increase.

3'(2') Site is not suitable for white pine .... End

If the site is not suited to growing white pine, management could proceed without specific regard to *Ribes*.

4(2) Stand averages less than 35 feet in height 18

4'(2) Stand averages more than 35 feet in height 5

Trees more than 35 feet in height are too tall for accurate canker counts, which are necessary to calculate the rust index. Rust status information is more important in this size class. Some of the trees in these stands may be merchantable or approaching merchantability, which could significantly alter management opportunities.

5(4') Trees are not of sufficient size to support commercial thin or salvage 11

5'(4') Trees are of sufficient size to support commercial thin or salvage 6

6(5) Stand is overstocked 8

6'(5) Stand is not overstocked 7

7(6') Insignificant volume loss expected due to mortality within 20 years or before scheduled harvest (D) — **No Intermediate Treatment Suggested** .... End

7'(6') Significant volume loss expected due to mortality within 20 years or before scheduled harvest (D) — **Consider Salvage of High-Risk White Pine or Shortened Rotation of Stand** .... End

8(6) Stand will not be overstocked in 20 years according to projected mortality from rust status survey (D) 7

8'(6) Stand will be overstocked in 20 years according to projected mortality from rust status survey (D) 9

9(8') Expected blister rust mortality from rust status survey is insufficient to accomplish desired stocking (A, C, D) — **Consider Thinning** .... End

Moderate high thinning removing 30 to 40 percent of the basal area for sawlog volume production also may reduce potential rust hazard through *Ribes* management (G).

9'(8') Expected blister rust mortality from rust status survey is sufficient to accomplish desired stocking (A, C, D) 10

10(9') **Consider Allowing Blister Rust to Accomplish Thinning**

If (1) sufficient white pine are expected to die to achieve the desired stocking level, and (2) they will die early enough to avoid significant growth reduction in the stand due to overstocking, it may be more economical to allow blister rust mortality to accomplish the stocking reduction.

10'(9') **Consider Thinning; Removing High-Risk White Pine**

Moderate high thinning removing 30 to 40 percent of the basal area, or light selection thinning removing about 20 percent of the basal area, has produced best results for sawlog production (C). Moderate high thinning may have the additional benefit of reducing *Ribes* population potential (G).

11(5) Stand is not currently adequately stocked 15

Judgment should be based on site, species, and "normal" attrition in the absence of blister rust and on management objectives. The influence of blister rust infections on currently living trees is considered in key pair 12 for stands otherwise adequately stocked.

11'(5) Stand is currently adequately stocked 12

12(11') Stand will not be adequately stocked in 20 years based on rust status (D) 14

If, after application of rust status data, the stand is not expected to be adequately stocked in 20 years, rehabilitation options will be tested.

12'(11') Stand will be adequately stocked in 20 years based on rust status (D) 13

After application of rust status data, the stand is expected to retain sufficient stocking in 20 years. The stand may require thinning.

13(12') Stand will not be sufficiently overstocked to result in significant growth loss before commercial thinning size is achieved — **Consider Deferring Treatment** .... End

If stocking is appropriate for the stand age considering mortality projected in key item 12', action can probably be deferred in this stand.

13'(12') Stand will be sufficiently overstocked to result in significant growth loss before commercial thinning size is achieved — **Consider Thinning** (A, G) .... End

Few new lethal infections are likely to be produced in trees this size.

Overstocked stands of this age probably have few *Ribes* bushes remaining so revitalization of *Ribes* plants is not a concern. But, rust hazard for the site could be greatly increased by burning thinning slash thus causing *Ribes* seed to germinate. This increase in hazard would likely carry through into the next rotation. Abundant seed would be deposited before crown closure created sufficient shade to kill the *Ribes* plants.

14(12) Stand rehabilitation will give adequate stocking in 20 years based on rust status (D) 17

Rust status survey will give an estimate of survival and treatment opportunities. Both pruning and canker excision are considered together in this key pair.

14'(12) Stand rehabilitation will not give adequate stocking in 20 years based on rust status (D) 15

You may decide to harvest the existing stand or rehabilitate some of the present stand and interplant to attain full stocking.

15(11)(14') Start over (F) 32

If stand is greatly understocked, you may find it more economical to harvest any merchantable trees and regenerate than to allow the site to remain understocked. You are directed to key pair 32 for regeneration stock type selection. Slash treatment may significantly alter rust hazard (B, G).

15'(11)(14') Interplant (F) 16

Western white pine (A) and other species may be planted beneath an understocked overstory allowing survivors of the present stand to reach merchantability while the site is being regenerated.

16(15') Rehabilitate white pine (E) 32

This may include pruning alone or both pruning and excising to bring many of the present trees to merchantability. Results of the rust status analysis should aid in deciding whether, and by what means, to rehabilitate. You are referred to pair 32 for white pine stock selection.

16'(15') Do not rehabilitate white pine 32

You may find it most feasible to retain any trees from the present stand that survive without treatment until they are merchantable. You are referred to pair 32 for white pine stock selection.

17(14) Pruning branch cankers will give adequate stocking in 20 years (D) — **Consider Pruning** (E) ..... End

If pruning will allow you to carry sufficient stocking to merchantability (which may be sooner than 20 years), this procedure may be economically feasible.

17'(14) Pruning branch cankers will not give adequate stocking in 20 years — **Consider Both Pruning and Excising** (E) .... End

Having passed to this pair through key item 14, rust status survey data have shown that pruning and excising together are required to retain adequate stocking. Although this branch of the key terminates with the alternative to prune and excise, you should examine the situation carefully before deciding to do so. If expected residual stocking of all desirable tree species, after mortality, approaches adequate stocking, it is probably not economically feasible to prune or excise cankers. Stand rehabilitation is biologically feasible and potentially most economically feasible in this size class of trees.

18(4) Mean stand age of white pine is greater than 10 years. 23

18'(4) Average stand age of white pine is 5 to 10 years 19

From key item 4, stands are separated based on usefulness of the rust index to estimate rust hazard and on reasonable management options for the respective age groups.

19(18') Less than 10 percent infected (D)—check again at age 15 to 20 years .... End

This is a sufficiently low level of infection for blister rust to be of minor concern at present. The stand should be checked again at age 15 to 20 years to see if the situation has changed.

19'(18') More than 10 percent infected 20

If this infection exceeds 10 percent, you should take a closer look to decide if some timely action could reduce losses.

20(19') Stand will be adequately stocked in 10 years (D) .... End

Ten years is about as long a period as can be reasonably predicted based on the percent-infected data collected in this young age class. Stand should be checked again at 15 to 20 years of age to make a more accurate prediction of survival.

20'(19') Stand will not be adequately stocked in 10 years 21

Pruning and rust hazard reduction (through *Ribes* population reduction) are explored for stocking maintenance.

21(20') Stand would be adequately stocked by pruning (D) — **Consider Pruning** (E) .... End

Particularly if unusually high infection rate resulted from a "wave-year" phenomenon, and most cankers are presently in a prunable condition, this may be an excellent opportunity to save a stand. *Ribes* population reduction may be applied as needed to protect the pruning investment (B, G).

21'(20') Stand would not be adequately stocked by pruning 22

If adequate stocking cannot be retained, it may be increased through interplanting or removal of the present stand and regeneration of better-suited stock.

22(21') Interplanting with resistant white pine or other species is considered 32

Resistant white pine may be planted if rust hazard level is 4 or lower. *Ribes* population reduction may be applied to reduce the hazard and improve survival of residual white pine (B, G).

22'(21') Removal of stand and site regeneration is considered 32

If infection rates are too high to treat the stand to retain adequate stocking (or if you decide not to treat), it may be better to start over with only 5 to 10 years invested in the stand than to carry a poorly stocked stand to rotation age. Resistant white pine and/or other tree species may be regenerated.

23(18') Stand not adequately stocked in 20 years according to rust status (D) 25

Judgment whether the stocking is adequate, as projected in 20 years from rust status data, should be based on site, species mix, "normal" attrition in the absence of blister rust, and management objectives.

23'(18') Stand adequately stocked in 20 years according to rust status (D) 24

24(23') Stand not overstocked — **Consider Deferring Treatment** .... End

If the stand will be adequately stocked in 20 years and it is not currently overstocked, there is no need for action now.

24'(23') Stand overstocked — **Consider Thinning** .... End

If rust hazard level (B) is 1 (very low), it is unlikely that stocking reduction will greatly increase infection frequency. If rust hazard exceeds this level, however, stocking reduction can result in dramatic increases in infection frequencies. In this case, thinning or other activities resulting in reduced stocking should be delayed to 25 to 30 years of age (C). Pruning may also be applied with thinning to limit increases in lethal infections (C). Slash treatment may affect rust hazard (G).

25(23) Adequate stocking can be achieved in 20 years by pruning (D) — **Consider Pruning** (E)..............End

If results of a rust status survey indicate that a sufficient number of trees can be saved by pruning, you may find it economical to do so.

25'(23) Adequate stocking cannot be achieved in 20 years by pruning 26

If rust status survey shows that too few trees can be saved by pruning, you may be able to reduce *Ribes* populations as well as prune and thereby achieve adequate stocking.

26(25') Adequate stocking can be achieved by pruning and *Ribes* population reduction (D) — **Consider Pruning** (E) **and Reducing *Ribes* Populations** (G) ....End

By the combined effects of pruning to reduce current infection rates, and *Ribes* population reduction to reduce future infection rates, you may be able to retain adequate stocking.

26'(25') Adequate stocking cannot be achieved by pruning and *Ribes* population reduction 27

If too many infections have reached stems for pruning and *Ribes* population reduction to sufficiently reduce mortality rates, some stands may be economically excised as well. This is particularly true for stands with marginal stocking with a large proportion of trees savable by excision.

27(26') Adequate stocking may be achieved by pruning, excising (D), and *Ribes* control (F) — **Consider Pruning, Excising, and Reducing *Ribes* Populations** (E, G) ....End

Whenever excising is done, pruning should be done in conjunction. The *Ribes* population should be considered in deciding whether to treat the stand. Large *Ribes* populations may place the pruning and excising investment in jeopardy. *Ribes* population reduction may be feasible if populations exceed 25 bushes per acre (B, G).

27'(26') Adequate stocking cannot be achieved by pruning, excising, and *Ribes* population reduction (D) 28

Alternatives to achieve adequate stocking by replacing the stand or interplanting are considered.

28(27') Starting over is considered (F) 32

Current stand would be slashed and site prepared for planting or natural seeding.

28'(27') Interplanting with rust-resistant white pine or other species is considered (F) 29

If sufficient numbers of trees will be retained with or without treatment, you may opt to hold all or a portion of the current stand while interplanting to increase stocking.

29(28') Pruning, excising and/or reducing *Ribes* population is considered (E, G) 32

You have already explored the feasibility of these intermediate treatments. You may still find that pruning, pruning with excising, or *Ribes* population reduction will increase survival of residuals. Effects of *Ribes* population reduction on the fate of interplanted white pine should be examined as well.

29'(28') Pruning, excising and/or reducing *Ribes* population is not considered (E, G) 32

If you decide not to treat the current stand nor reduce *Ribes* populations, you may want to proceed to item 32 in the key for selection of white pine stock if you plan to interplant with white pine.

30(1) Site not suitable for white pine (A) — **Consider Regenerating to Other Species** .... End

Site suitability is based on properties of the site and silvical characteristics of western white pine as summarized in appendix A.

30'(1) Site suitable for white pine 31

This key pair begins the second major grouping. Sites that are to be regenerated are treated here to select proper levels of resistance of white pine stock to match the site rust hazard.

31(30') Planned for cutting 42

If the stand has not yet been cut, there may be opportunities to keep rust hazard lower by modifying harvest and site preparation methods.

31'(30') Already clearcut 32

This also assumes site preparation has been completed.

32(15)(16)(16')(22)(22')(28)(29)(29')(31')(44')(49) rust hazard level greater than 1 (B) 35

This is a major converging point in the key. When a recommendation for planting stock is wanted, you are directed to this key pair.

Stock type recommendations: These items treat stock recommendations for increasingly hazardous sites. Recommendations for mixing rates such as "Regenerate up to 75 percent F_1 means that white pine should make up no more than 75 percent of the stand composition at the time of stand establishment and that the resistance level should be equal to that of F_1 stock as explained in appendix F. This does not imply that the final stand at rotation age will contain 75 percent white pine. Attrition rate of white pine is expected to be greater than that of other species. Refer to appendix F for explanation of stock type abbreviations.

32'(15)(16)(16')(22)(22')(28)(29)(29')(31') rust hazard level 1 (B) 33

33(32')(43) Pure stand of white pine: **Regenerate GCA OP or F_1** .... End

33'(32')(43) Mixed species stand 34

34(33) **NonGCA OP; up to 75 Percent** (F) .... End

34'(33) **Wild Type; to Less than 50 Percent** (F) .... End

35(32) Rust hazard level greater than 2 38

35'(32) Rust hazard level 2 36

36(35')(46) Pure stands of white pine: Regenerate **F_1 OR F_2** (F) .... End

36'(35')(46) Mixed species stands 33

37(36') **GCA OP; up to 75 Percent** (F) .... End

37'(36') **NonGCA OP; up to 50 Percent White Pine** (F) .... End

38(35)(50) Rust hazard level greater than 3 41

38'(35)(50) Rust hazard level 3 39

39(38')(48) Pure stands of white pine: **Regenerate F_2** (F) .... End

39'(38')(48) Mixed species stands 40

40(39') **F_1; up to 50 Percent of Stand** (F) .... End

40'(39') **GCA OP; up to 50 Percent of Stand** (F) .... End

41(38) Rust hazard level 5: **Consider Regenerating Species Other Than White Pine or Reducing *Ribes* Populations** (G) .... End

41'(38) Rust hazard level 4: **Regenerate Up to 50 Percent with (52) F_2** .... End

42(31) Rust hazard level (B) greater than 1 45

Rust hazard level information may be useful both for white pine stock selection and to help in deciding whether harvest or site preparation methods may be altered to avoid actuating potential *Ribes* populations.

42'(31) Rust hazard level 1 43

It may be particularly desirable to use white pine seed trees on these sites to aid in maintaining genetic diversity of white pine.

43(42') Clearcut regeneration method is considered 33

If clearcutting is considered, you are referred to the key section (item 33) on white pine planting stock selection. This does not preclude natural regeneration on the clearcut site if the rust hazard is very low; item 34' recommends that less than 50 percent of a stand be wild type white pine. This is to ensure proper stand closure to shade out *Ribes* and prevent prolonged exposure of white pine in the stand to heavy rust inoculum loads.

43'(42') Other regeneration methods are considered 44

Very low hazard sites such as these provide many options for management that would raise the prospects for severe infection on higher hazard sites (C, H).

44(43')(46')(50') Natural regeneration is considered .... End

If natural regeneration methods are used, the resistance level of white pine in the regeneration stand will be approximately equal to that of the tested wild-type (see appendix F) stock. You can probably manage white pine as somewhat less than 50 percent of the stand and still attain at least 50 percent stand closure at 20 years of age. With higher rust hazard levels or larger proportions of white pine, you are less assured of success. Intermediate treatments such as pruning or *Ribes* population reduction may still make the white pine manageable in these stands. The cost of more intensive management may not be justifiable when compared to planting costs for establishment of a rust-resistant stand.

44'(43')(46')(50') Regeneration by planting is considered 32

If the site is to be planted, you are referred to key pair 32 for selection of white pine planting stock.

45(42) Rust hazard level greater than 2 47

45'(42) Rust hazard level 2 46

46(45') Clearcutting method is considered 36

46'(45') Other silvicultural methods are considered 44

Considerations are presented in key pair 44.

47(45) Rust hazard level greater than 3 51

47'(45) Rust hazard level 3 48

48(47') Clearcutting method is considered 39

At this hazard level, natural regeneration to include white pine is not recommended.

48'(47') Other silvicultural methods are considered 49

Modification of harvest methods can reduce actuated *Ribes* populations well below the estimated potential.

49(48')(52')(53') Low disturbance logging method (G) 32

Logging on snow can result in actual *Ribes* population 95 percent lower than potential population due to nongermination and subsequent inactivation of *Ribes* seed. See appendix G for discussion. Rust hazard level should be reassessed following logging to determine white pine stock type for regeneration.

49'(48')(52')(53') Three-step shelterwood method 50

This silvicultural method may significantly reduce site hazard by stimulating *Ribes* germination and subsequently shading out *Ribes* plants before much seed deposition has occurred. Refer to appendix G for discussion.

50(49') More than one *Ribes* per acre 3 to 10 years after first cut (H) 35

Ribes seed germination should be near maximum about 3 years following site preparation (or cutting if there was no site preparation). Up to about 10 years following germination, *Ribes* populations generally remain stable. After this time, *Ribes* populations should begin to decline as crown closure reduces ground irradiation. If after the first cut, *Ribes* populations are still too high for natural regeneration of white pine, white pine seed trees should not be used. If a white pine component is desired, rust-resistant white pine could be planted.

50'(49') Less than one *Ribes* per acre 3 to 10 years after first cut (H) 44

If *Ribes* peak populations are less than one per acre, you may opt to regenerate wild-type white pine using the shelterwood system. Wild-type white pine regeneration should not exceed 50 percent of the stand when established.

51(47) Rust hazard level 5 53

Silvicultural methods that reduce germination and survival of *Ribes* may lower the rust hazard sufficiently to manage resistant white pine.

51'(47) Rust hazard level 4 52

52(51') Stand is to be clearcut 41

Clearcutting, particularly with broadcast burning, will not lower the rust hazard.

52'(51') Other silvicultural methods to be used 49

With this high rust hazard level, alternative harvest and site preparation methods could be considered to reduce actual hazard.

53(51) Stand is to be clearcut. **Consider Regenerating Species Other Than White Pine or Administering Post Harvest *Ribes* Population Reduction** (H) .... End

This level of rust hazard exceeds limits for even the most resistant white pine stock available. Consider managing species other than white pine on these sites unless *Ribes* populations are reduced.

53'(51) Other silvicultural practices are considered 49

Alternative harvest and site preparation methods could significantly reduce the blister rust hazard on these sites.

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Figure 4—(A) Zone of tree crown in which new infections have most potential to reach the stem (highest probability of lethality). One- and 2-year-old needles are less than 24 inches away from the stem. (B) Basal stem canker. This canker is girdling about 50 percent of the circumference of the stem. Diameter of the stem is measured at point of greatest girdle (broken line) for rust status data collection. (C) Stem canker. This canker is girdling about 40 percent of the circumference of the stem. Diameter of the stem is measured at point of greatest girdle (broken line) for rust status data collection.

Figure 4 (Con.)—(D) Excision of a stem canker. A tree scribe is used to cut a channel through the cambium at 1 inch beyond the visible margin of the canker. (E) Margin of stem canker. The visible margin of this canker (arrow) includes a band of discolored bark well beyond the obviously dead bark. (F) Margin of stem canker. The visible edge of this canker (arrow) is close to the obviously dead bark.

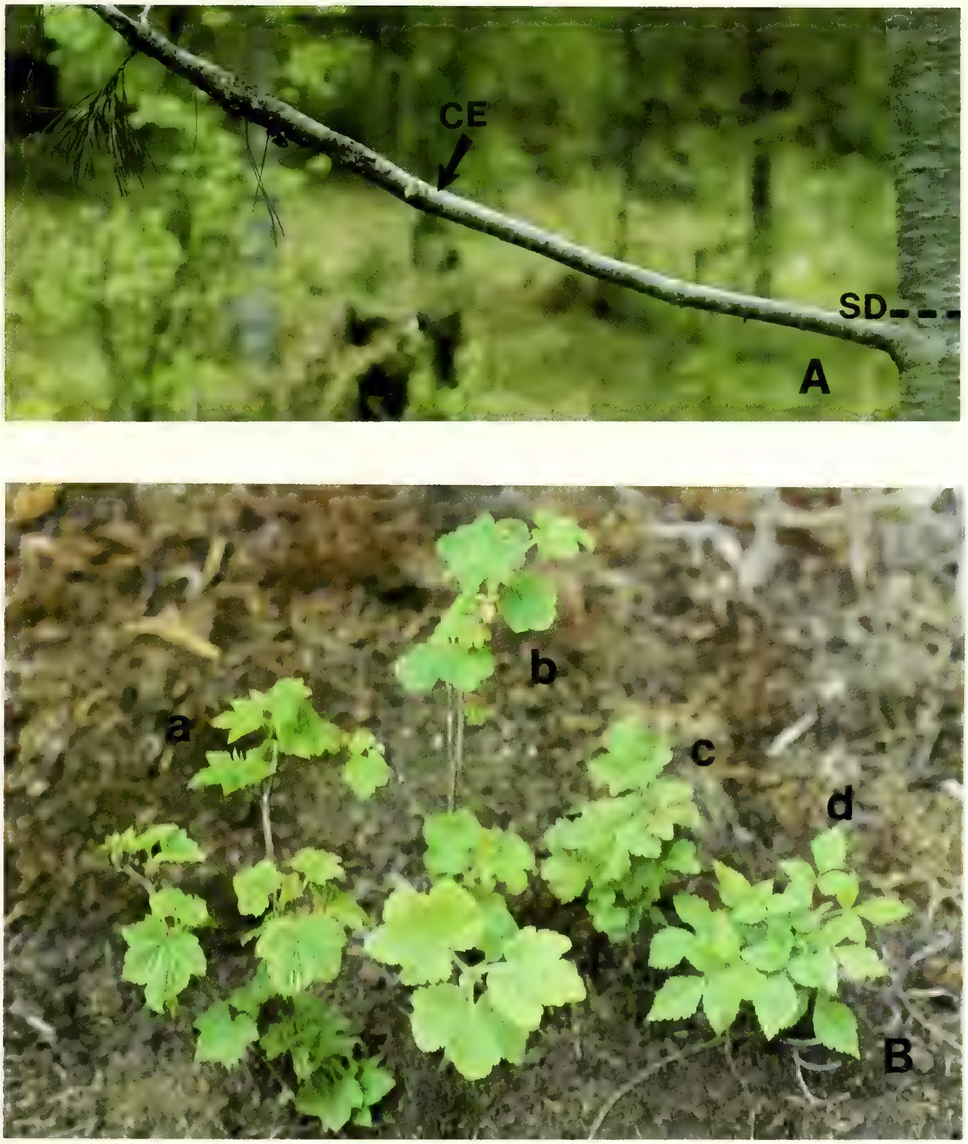

Figure 5—(A) Branch canker measurement. When collecting rust status data, measure the length of branch from the nearest margin of the canker (CE) to the stem. Measure stem diameter immediately above the whorl (SD). (B) *Ribes* and common species easily confused with *Ribes*—(a) *Rubus parviflorus,* thimbleberry; (b) *Ribes viscosissimum,* sticky currant; (c) *Ribes lacustre*, prickly currant; (d) *Rubus idaeus*, red raspberry.

Figure 5 (Con.)—(C) *Ribes lacustre.* (D) *Ribes viscosissimum.*

APPENDIX A: WESTERN WHITE PINE SILVICS

Several reviews of western white pine silvics and silviculture have been published (Fowells 1965; Graham and others 1984; Wellner 1962, 1973). The species has received a great deal of research, and much is known about its silvical characteristics and culture. It grows in climates typified by short, dry growing seasons and heavy winter snowfall (Fowells 1965; Wellner 1962). Western white pine grows equally well on a great variety of soil types (Ferrell 1955); however, soil moisture is an important limiting factor. Growth is best on deep, well-drained, medium- to fine-textured soils with high water-holding capacity (Copeland 1956, 1958).

In Idaho and Montana, western white pine grows between 2,000 and 6,000 feet above sea level. The best stands are found in wide river bottoms; gentle lower slopes and northerly slopes; and in gently rolling country of the Priest, Coeur d'Alene, St. Joe, and Clearwater River basins (Fowells 1965).

Fire has left its mark at some time or other on practically every acre of western white pine forests (Haig and others 1941). Western white pine is a fire species and owes it prevalence mainly to fires that have destroyed stands and allowed white pine to become established. Among its associates, western white pine is rated intermediate in fire resistance (Flint 1925).

Populations of western white pine in the Rocky Mountains, Northern Cascades, and northern coastal areas are notably uniform and appear to be genetically differentiated from populations in the Sierra Nevada (Rehfeldt and others 1984). Transition zone populations from the central and south Cascades were intermediate in character between the northern and southern groups of populations. Within the northern and southern groups, geographic patterns of variation were weak and elevational patterns were not found. Variation within populations and families was large. Most variation within northern Idaho populations probably is due to phenotypic plasticity rather than genetic differentiation (Rehfeldt and others 1984).

Western white pine occurs as a major seral in six phases within the hemlock series and one phase within the subalpine fir series in northern Idaho. In addition, it occurs as a minor seral on 22 of 65 phases of grand fir, western redcedar, western hemlock, and subalpine fir series identified by Cooper and others (1987) for northern Idaho.

In western Montana it occurs as a major seral in the *Clintonia uniflora* phase, *C. uniflora* habitat type of western hemlock, and in some areas of subalpine fir—*Clintonia uniflora, Aralia nudicaulis* phase (Pfister and others 1977). As a minor seral in Montana, western white pine was recognized by Pfister and others in 14 phases in grand fir, western redcedar, western hemlock, and subalpine fir series.

Western white pine is about equal in shade tolerance to Douglas-fir. It is more tolerant than western larch and lodgepole pine and less tolerant than Engelmann spruce, grand fir, western hemlock, and western redcedar (Baker 1949).

Regeneration

Both natural and artificial regeneration of western white pine have high success rates. Mineral soil, burned or unburned, is better than duff surfaces for seed germination and for planted seedling establishment (Wellner 1962).

Western white pines produce mature cones in the field as early as age 10. Although monoecious, trees remain predominantly female until about age 20 (Bingham and others 1972). Trees tend to be consistent in their ability to produce cones and set seeds (Bingham and Rehfeldt 1970). Long-term yields for 25- to 75-year-old trees average 28 cones with 100 filled seed per wind-pollinated cone. Yields vary among mother trees, localities, and seed years. Cone crop cycles are generally 3 to 4 years between major yields (Bingham and Rehfeldt 1970).

Seed dispersal is effective up to about 400 feet from parent trees. Seedling establishment is favored by partial shade on severe to moderately severe sites. On the more sheltered sites, such as north slopes, light shade to full sun is best for seedling establishment (Haig and others 1941). Factors contributing to seedling mortality were discussed by Haig (1936) and Haig and others (1941).

Regeneration methods silviculturally favorable to seedling establishment include clearcutting, seed tree methods, and shelterwoods. Western white pine seedlings require 30 to 40 percent of full sunlight for establishment (Wellner 1962). Once well established, western white pine grows best on all sites in full sunlight (Haig and others 1941). Shade of any amount favors its more tolerant associates.

Overwood densities of 15 to 40 trees per acre were recommended by Graham and others (1984) for shelterwood regeneration methods in the western white pine type. Four to six seed trees per acre were considered sufficient for seed tree methods in this type.

When seed tree or shelterwood regeneration methods are employed, seed trees should be removed within about 20 to 30 years to avoid suppressing growth of white pine regeneration (Moss and Wellner 1953).

Western white pine seedlings grow slowly at first. Dominant seedlings growing in the open require about 8 years to reach a height of 4.5 feet on excellent sites and about 16 years on poor sites. Once established, they increase rapidly in height growth (Wellner 1962). By age 20, the height of the average dominant white pine on excellent sites is about 16 feet and on the poorest sites about 10 feet (Haig 1932).

Intermediate Stands

Dominance and stand composition are determined during the period between seedling establishment and about 30 years of age. They change little thereafter unless intermediate treatments are imposed (Watt 1960).

Mixed-species stands in the white pine type often have naturally high stocking densities. Number of trees per acre on sites with a 50-year site index of 40 are listed by Haig (1932) as 11,500 at age 20, 3,020 at age 60, and 980 at age 120. On excellent sites, index 80, trees per acre

were 2,050 at age 20, 540 at age 60, and 235 at age 120. At these stocking densities trees are generally small. For example, on good sites (index 60) at age 120, trees averaged 12.2 inches d.b.h. In these stands, 60 percent of the trees were under 13 inches d.b.h. and 27 percent were under 7 inches d.b.h.

Western white pine is slow to respond to thinning, particularly beyond about 30 years of age (Deitschman 1966). It grows equally well over a range of stocking densities, so it can be managed with a heavy residual stocking of 400 to 500 trees per acre following thinning at 20 to 25 years of age (Graham 1983). If the stand is not significantly heavier stocked than this prior to thinning, little growth response occurs.

Wellner and Boyd (1960) found diameter growth response following thinning in mature stands to depend largely on tree vigor.

Western white pine is slow to shed lower branches, even in dense stands (Rapraeger 1939). Branches are retained 27 to 73 years (Paul 1938), with small branches persisting as long or longer than do large-diameter branches. Pruning can greatly improve the quality of western white pine wood if performed at about 20 to 30 years of age. But in the Western States pruning is rarely done because it is not considered cost effective where wood quality improvement is the major goal.

Current and potential blister rust status and hazard are important considerations in thinnings, prunings, and regeneration operations. Refer to appendixes B, C, D, E, and F for more information on these.

Growth and Production

Although western white pine starts slow, by about 40 years of age it will outgrow Douglas-fir and western larch on good to excellent sites (Watt 1960). At 70 years on good white pine sites, larch often begins to drop out of stands due to competition, and Douglas-fir begins to decline due to root disease (Watt 1960). Western white pine retains its advantage until about 120 to 140 years when the more tolerant species gain in position (Watt 1960). Cubic foot increment of western white pine stands culminates at about 100 to 120 years (Davis 1942). According to Haig (1932), 90-year-old western white pines can be expected to average 9.3 inches d.b.h. and 73 feet in height on site index 40 (50-year base). At site index 80, they average 18.3 inches and 145 feet.

A contemporary discussion of economics of managing western white pine on contrasting sites is presented by Manning and Howe (1983). Greater stocking density and more rapid growth compared to associated conifers contribute to the desirability of growing white pine, especially on good white pine sites.

Diseases, Insects, and Animal Pests

Western white pine has few important diseases. In Idaho and Montana, blister rust is generally the most damaging of these. But in some stands root disease caused by *Armillaria* spp., stem decay caused by *Phellinus pini*, or needle blight caused by *Dothistroma pini* var. *linearis* (Evans 1984; Shaw and Leaphart 1960) may have more impact than blister rust. Other less frequent root diseases, such as *Inonotus tomentosus, Heterobasidion annosum*, and *Phaeolus schweinitzii* may be locally important, (Hubert 1950); *Phaeolus schweinitzii, H. annosum*, and *Phellinus* weirii can cause considerable cull from butt rot.

Root disease caused by *Armillaria* spp. is second to blister rust as a disease of western white pine. *Armillaria* can kill large numbers of trees, particularly saplings, in localized areas. Observations suggest that most *Armillaria*-caused mortality of western white pine occurs between 15 and 30 years of age. This is in contrast to Douglas-fir or true firs, which continue to decline throughout the rotation. Morrison (1981) ranks western white pine as moderately susceptible to *Armillaria* in parts of British Columbia adjacent to Idaho and Montana.

Western white pine is often a preferred species for culture on *P. weirii*-infested sites in northern Idaho and western Montana where Douglas-fir and true firs are severely affected (Smith and Sheldon 1984).

Atropellis pinicola stem cankers occasionally cause some loss in form or mortality.

Considerable mortality of first-season germlings may result from damping-off fungi, particularly *Fusarium* spp. (Haig and others 1941). *Pythium* spp. may also be important in damping-off containerized seedlings (James 1985).

Western white pine is not a primary host for any dwarf mistletoe species. Occasional crossover of *Arceuthobium laricis* from western larch or *A. americanum* from lodgepole pine occurs.

Western white pine has few serious insect pests. Mountain pine beetle is important in old-growth stands, killing trees larger than 10 inches d.b.h. It is unlikely to be a major problem in stands managed on rotations shorter than 100 to 120 years.

Seed production from western white pine may be seriously reduced by mountain pine cone beetles (*Conophthorus monticolae*). Localized populations have virtually eliminated harvestable seed in orchards in some years (Dewey and Jenkins 1982). Similar impacts have been reported in natural stands (Barnes and others 1962).

Animals occasionally do serious damage to western white pine. Seedlings are girdled or severed by pocket gophers and rabbits. Seedlings may be heavily browsed by deer and elk, particularly in winter range areas. Porcupines and tree squirrels occasionally girdle saplings or tops of pole-sized trees, and bear clawing can be locally important, causing stem scarring (Molnar and McMinn 1960).

APPENDIX B: RUST HAZARD

Infection Intensity

Stillinger (1943) studied the relationship between various factors and rate of increase in blister rust infections in stands. In conclusion he stated, "The rate at which the rust increases is the resultant of all the factors on a particular site which may have any influence upon the increase of the rust infection. For this reason it may be used as an index to the favorableness of the particular site for the development of the rust as well as a guide to the effectiveness of control in relation to the *Ribes* population." Stillinger used "cankers per tree" as his measure of rust increase. Unfortunately, this measure does not account for changes in leaf area (target area) as trees grow. The rate of infection per unit leaf area may remain constant or even decline, while the rate of accumulation of cankers per tree increases.

Buchanan (1938) counted the numbers of needles on young western white pines of a variety of sizes. Infection rates were then expressed by Buchanan and Kimmey (1938) as cankers per 1 million needles to give a more accurate measure of rust intensification in stands.

McDonald and others (1981) took this method a step further by developing a model for pine target using tree height to estimate numbers of needles. Combining this with tree age, they calculated annual target for a given tree. This provided an index to rust infection rate based on cankers per thousand needles per year.

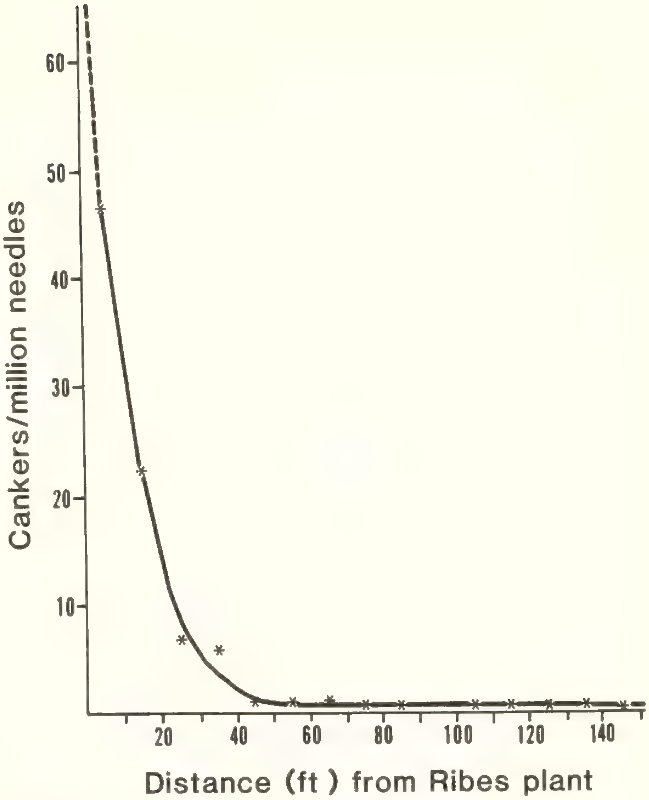

Figure 3—Average number of cankers per million needles on 4,600 western white pine saplings within 10-foot concentric zones around infected *Ribes* plants. Redrawn from Buchanan and Kimmey (1938).

Ribes Influence

Number and size of *Ribes* and number of trees per acre were found by Stillinger (1943) to account for 51 percent of the variation in rate of infection (as cankers per tree). Of this, number of trees had little influence, and *Ribes* bush size showed no direct correlation with rate of infection. Thus, the number of *Ribes* bushes per acre accounted for most of 51 percent of the infection rate differences expressed as cankers per tree.

Trees growing nearest to *Ribes* bushes have been shown to bear proportionally greater numbers of cankers. In a study reported by Buchanan and Kimmey (1938) within concentric zones of 0 to 50 feet and 50 to 100 feet from a *Ribes* bush, 0.49 and 0.08 canker per tree was produced respectively in a 2-year period. Stillinger (1943) presented similar data in which 20-year-old trees within 20 feet of an isolated *Ribes* plant had an average of 31 cankers, while trees 61 to 80 feet from the same *Ribes* plant averaged only one canker. Buchanan and Kimmey (1938) demonstrated that the intensity of infection fell to an almost negligible value between 50 and 60 feet from the *Ribes* bush, irrespective of the intensity nearer the bush (fig. 3).

A lethal canker is one which caused or has a high probability of causing a tree to die. Likelihood of lethal infection increases as numbers of cankers increase. Stillinger reported that 84 percent of the trees within 20 feet of a *Ribes* bush were infected and all of these had lethal infections. At 61 to 80 feet from the bush, however, 46 percent were infected, with only 13 percent lethally infected.

The influence of *Ribes* populations is especially important in young stands, up to age 20 or 30 years—the stage at which they are most vulnerable. During these years much of the foliage of a tree is within the zone in which infection is most likely to lead to death of the tree. An infection occurring in a needle more than 24 inches from the bole has a very small chance of reaching the bole. Among circumstances which lead to nonlethal infections, the majority of such cases involve cankers occurring too distal on a branch to reach the bole before girdling and killing the branch, or before the branch dies naturally from insufficient light, or before inactivation of the canker occurs (Hungerford 1977; Kimmey 1969). White pine needles seldom survive more than 4 years (Buchnan 1938), so infections in 3-year-old needles rarely produce cankers (McDonald and others 1981). A zone of foliage from the top of the tree down to where the 1- and 2-year-old needles are more than 2 feet from the bole will account for most of the lethal infections occurring at any point in time (fig. 4A, center of book). This zone changes position as the tree grows. As the tree crown enlarges, proportionally fewer infections occur within this zone.

Rust Hazard Estimation

Rust infection intensity can vary considerably from one stand to the next (Goddard and others 1985; McDonald 1979). Local weather patterns (Van Arsdel and others 1959) and onsite *Ribes* populations (Moss and Wellner 1953) are generally most responsible for this variation. Occasionally, peculiar air currents have been shown to carry rust spores from concentrated *Ribes* populations to distant white pine stands. Lloyd (1959) reported such a situation occurring in a northern Idaho stand. *Ribes* had been eradicated from the site, and yet the 20-year-old white pine plantation was incurring many new infections. Airflow patterns were studied, revealing that rust spores were carried over a ridge via warm air movement upward from a lake. Noting that blister rust sporidia seldom are carried more than 900 feet from *Ribes* plants to pines, Lloyd concluded that the peculiar air currents created by the lake accounted for the unexpected infection.

Stillinger (1943) defined rust hazard as "the favorableness of the particular site for the development of the rust." Local weather patterns, *Ribes* populations, and occasional unusual air currents such as were studied by Lloyd are the major factors contributing to rust hazard.

Rust hazard estimates are best made on the basis of the rust index (cankers per thousand needles per year) calculated from at least 10 years' accumulation of infections in a stand with white pines less than 35 feet tall.

General ranges of rust indices are used to define rust hazard levels 1 through 5 (table 1).

Rust hazard estimates from *Ribes* populations are less reliable than those based on rust index and should be restricted to use for planting stock selection where an index is unattainable. Only the rust index is sufficiently sensitive for rust hazard estimates to develop management plans for existing stands of white pine.

Measuring Rust Index

One hundred trees that are at least 10 years of age but less than 35 feet in height are sampled in each stand. Height, number of whorls, and number of rust cankers are recorded for each tree (table 2). The rust index computer program calculates the index and 20-year mortality predictions.

Rust index is a sensitive measure of rust hazard. It provides the best basis for stock type selection to regenerate a site. Rust index also provides a future infection rate estimate for the rust status program mortality model (appendix D). This, with other rust status data, projects mortality rates of white pine stands for up to 40 years hence.

Rust Hazard Estimated From *Ribes* Populations

If stands meeting the requirements for rust index measurement are not available on or near the site, measurement of *Ribes* populations (appendix H) often will provide an adequate estimate of rust hazard for regeneration stock type selection.

Many sites support naturally low *Ribes* populations, less than one bush per acre (USDA 1950). Much of the infection in stands on these sites is the result of long-distance spread (greater than 1,000 feet from *Ribes* bushes). Infection intensities on these sites are generally low. Wild-type (appendix F) western white pines may be managed as a component of mixed stands on these sites, although with less assurance of survival than white pines with higher levels of resistance. Less certainty of success using wild-type white pines should be weighed against potentially lower cost and greater flexibility of the natural regeneration methods possible with wild-type stock.

As onsite *Ribes* populations increase, their relative influence on infection intensity increases. Spores spreading from local bushes account for an increasingly greater proportion of the infection in the pine stand.

Compared with infection intensities and mortality on a variety of sites, onsite *Ribes* populations are associated with rust hazard levels as presented in table 3.

These *Ribes* population/rust hazard level relationships were estimated on the basis of considerable data from northern Idaho and western Montana stands collected by the Forest Pest Control unit of the Northern Region, USDA Forest Service, in the mid-1960's and from numerous smaller surveys and studies conducted by the Intermountain Research Station, USDA Forest Service.

Appendix H provides an explanation of methods for measuring *Ribes* populations.

Table 2—Rust index data suggested format

Tree No.	Height	No. whorls	No. cankers
	Feet		
1	7.5	12	3
2	9.3	19	0
3	8.7	15	0
4	12.9	11	1
5	10.1	20	6
:			
100	9.7	15	10

Table 3—Rust hazard estimation from onsite *Ribes* population

Ribes per acre	Rust hazard level
<1	1 very low
1-24	2 low
25-99	3 moderate
100-1,000	4 high
>1,000	5 very high

APPENDIX C: STOCKING REDUCTION

Precommercial Stands

Stocking control often will be necessary to optimize merchantable volume production. Since most naturally occurring stands in the white pine type will be overstocked when young, the first stocking reduction will often be precommercial at age 20 to 30.

Low thinning is currently the method most often used for precommercial thinning in the white pine type. Dominant and codominant trees are released by removing trees in the lower crown classes. Timing of precommercial thinnings may affect blister rust infection rates. Of key interest in our area is a report published by Hungerford and others (1982). Increased lethal cankering rates resulted from precommercial thinning of predominantly white pine stands. The stands were low thinned to 436 and 222 trees per acre when they were 10 to 20 years of age. Infection frequencies of thinned stands surpassed those of unthinned stands in the ensuing 5 years. Stands that had been both pruned and thinned had infection frequencies similar to control stands that were neither pruned nor thinned. Citing the need for a hazard rating system as the basis, they suggested that precommercial thinning in white pine stands be confined to stands with obviously low infection levels.

Increases in lethal infection rates following thinning are likely to be greater on high-hazard sites than on low-hazard sites (Hungerford and others 1982). Delaying thinning to 25 or 30 years of age may somewhat ameliorate the lethal infection increase effect of thinning in three ways: (1) stand diameters of white pines will be larger, improving the chances they will reach merchantability before being girdled by new cankers; (2) the trees may have fewer live branches in their lower crowns where most infections would normally occur; and (3) greater stand closure may have caused more of the shade-intolerant *Ribes* plants to die out.

Current lethal infection rates and rust hazard (appendix B) are important considerations in deciding when and how to accomplish a precommercial thinning.

In general, the better the site quality, the sooner competition becomes a limiting factor for white pine growth.

Graham (1983) suggested that white pine stands are most beneficially thinned between 20 and 25 years of age with respect to individual crop tree diameter growth. He recommended residual stocking densities of 400 to 500 trees per acre at this age. Hungerford and others (1982) recommended delaying thinning of predominantly white pine stands to approximately 25 to 30 years of age to allow time for rust selection pressure on white pine.

Deitschman and Pfister (1973) compared cleanings that favored western white pine and western redcedar at ages ranging from 8 to 16 years. Initial stocking in the mixed-species stands ranged from 21,000 trees per acre in an 8-year-old stand to 7,000 in a 16-year-old stand. Stocking was 3,500 to 1,600 trees per acre following the cleanings.

Deitchman and Pfister evaluated these treatments for meeting the goals of increasing proportion of white pine and western redcedar in the dominant and codominant crown classes and of increasing height and diameter growth. Ingrowth of western hemlock, grand fir, and western larch interfered with these goals somewhat, particularly in stands cleaned at an early age. White pine responded well and maintained its height advantage in all cleaned stands with the exception of an 8-year-old stand which had been moderately cleaned. Here, although white pine growth response was good, western larch remained an important competitor, outgrowing some of the white pines. White pine nearly completely dropped out of the uncleaned stand where western larch and lodgepole pine were strong competitors.

Where grand fir and western hemlock were primary competitors, white pine maintained nearly equal growth with these species until about 30 years of age after which it began decreasing in position.

Removal of grand fir and western hemlock overstory (which had been creating 75 percent shade conditions) and cleaning of the established regeneration to favor western white pine at age 15 resulted in significant gains in white pine growth. Average height of dominant and codominant white pines at age 45 was nearly 60 feet in treated plots compared with 15 feet in the unreleased, uncleaned plots. Moss and Wellner (1953) recommended releasing young white pine stands from overwood by age 20 to 30 years to avoid favoring the more shade-tolerant species.

Prescriptions involving stocking reduction in precommercial stands should take into account rust hazard and rust status. Grand fir, western hemlock, and western redcedar more effectively suppress *Ribes* than do Douglas-fir, western larch, and pines. Therefore, *Ribes* populations will decline most rapidly in heavily stocked stands with high proportions of grand fir, western hemlock, and western redcedar.

A variety of thinning or cleaning prescriptions may be used to accomplish stocking goals and suppress *Ribes* in young stands. Species composition, stocking, site quality, and *Ribes* population are considerations for design of such prescriptions. For example, high thinning may be used to maintain growth of the best codominants while retaining heavy stocking on the site to suppress *Ribes*. This, then, can be followed in later years by low thinning, if desired, to reduce stocking of intermediate and suppressed crown classes.

If lethal infection rates are high, the imminent mortality of white pine may be sufficient to reduce stocking to, or below, the desired level. Also, thinning or cleaning investments may be jeopardized by subsequent mortality from blister rust infection.

A rust status survey (appendix D) should be made separately or in conjunction with a prethinning or cleaning examination. This will provide necessary information on lethal cankers to develop a proper cleaning or precommercial thinning prescription.

White pines that are crop-tree candidates should be examined carefully for lethal infections, particularly in the basal whorl where cankers often are overlooked.

Commercial Stands

Foiles (1972) reported 10-year results of a commercial thinning study in western white pine stands on the Clearwater National Forest. He tested growth response and volume production from 87-year-old stands receiving light and moderate high thinning, light and moderate selection thinning, and no thinning. Basal area removed in thinning was 19 percent and 37 percent in light and moderate high thinning, respectively; 19 and 30 percent in light and moderate selection thinning, respectively. Average diameter growth was greatest and mortality was least following moderate high thinning. Selection thinning, particularly moderate intensity, resulted in excessive mortality of residuals. Light crown thinning was the best treatment of harvest-anticipated mortality while maintaining near maximum volume production.

In another study, low thinnings in 60-year-old, primarily white pine stands reduced basal area 25, 50, and 62 percent (Foiles 1955). Most of the trees cut during thinning were submerchantable. Thirty years after thinning, plots that had been reduced 25 and 50 percent in basal area had 22 and 2 percent greater net board foot volume, respectively, than unthinned plots. Low thinning, which reduced basal area by 62 percent, resulted in 16 percent less net board foot volume 30 years later compared with unthinned plots. Based on these results, Foiles recommended that low thinnings to maximize quantity and quality of volume production should reduce basal area by about 25 percent.

Stocking reduction in stands that are more than about 40 years of age is unlikely to result in significant increases in mortality before final harvest.

The time required for new, potentially lethal infections to cause mortality increases as tree diameter increases. For example, an 11.3-inch-d.b.h. tree is expected to survive 17 to 24 years after infection (Buchanan 1938). Before stocking is reduced, rates of new infection generally are low in well-stocked stands older than 40 years because surviving *Ribes* are restricted to open ridgetops and rock outcroppings where sufficient sunlight is available (Moss and Wellner 1953).

The type and intensity of thinning in mature stands can greatly alter rust hazard of sites for subsequent rotations. Refer to appendix G, *Ribes* Ecology and Management, for a discussion of this subject.

APPENDIX D: RUST STATUS

Rust status refers to a measure of the proportion of white pines that could benefit from pruning or canker excision. This measurement can be used to predict survival times of rust-infected white pines up to about 40 years hence.

Stands Greater Than 10 Years Old

Stands that are at least 10 years of age but average less than 35 feet in height offer the greatest opportunity for treatment to reduce mortality. A large proportion of the potentially lethal infections often are removable through pruning at this stage. If excision is done it is nearly always in combination with pruning, and gains from the two are additive.

For this size class of trees the rust status model predicts influence of new infections. The trees are still of a size at which new infections can cause significant mortality.

Trees taller than 30 feet may have progressed mostly beyond the stage in which pruning will significantly decrease mortality. But, excision may be even more feasible in trees this size. Individuals are presumably more valuable; stems are larger, allowing for removal of more bark in the excision process without exceeding the tolerable amount of girdle, and chances of new lethal infections are considerably lower. Mortality prediction by the rust status program mortality model for trees greater than 35 feet in height is minimally influenced by new infections.

A rust status sample should include at least 50 to 100 white pines in each stand. Depending on the size of trees, fixed 1/300-acre plots or variable plots giving about 2 percent coverage of the stand are recommended for sampling. Tree height, age, condition (live or dead), total number of cankers on tree, and measurements on the "most lethal" canker are recorded (table 4). The most lethal canker is that which is likely to kill the tree soonest. Priorities for most lethal cankers are:

1. Basal canker, a stem canker of which the lower end is less than 3 inches above ground line (fig. 4B, center of book).

2. Stem canker, a canker more than 3 inches above ground line; in the case of multiple stem cankers, that which has the highest percentage of girdle is measured.

3. Branch canker; the canker closest to the stem is measured.

Additional lethal cankers can be entered into the rust status model to improve accuracy of predictions. Up to 20 lethal cankers can be entered for each tree. Data required for each additional lethal canker will be the same as listed in table 4.

If the most lethal canker is:	**Record**
stem (fig. 4B&C, center of book)	1. percentage girdled; recorded to nearest 10 percent. Visually estimated or measured percent of circumference within canker.
	2. diameter of stem at center of canker
	3. within excisable zone - lower edge of canker >3 inches from ground and top edge of canker <6 feet above ground E = within excisable zone NE = not within excisable zone
branch (fig. 5A, center of book)	1. distance from nearest edge of canker to stem
	2. diameter of stem where branch attaches (immediately above whorl)
	3. within prunable zone - branch attached <8 feet above ground P = prunable NP = not prunable

Table 4—Rust status data format for stands greater than 10 years of age

Tree No.	Height	D.b.h.	Age	Condition[1]	Total Cankers	Lethal cankers measured	Stem Girdle	Stem Diameter	E[2]	NE[2]	Branch Distance	Branch Diameter	P[3]	NP[3]
	Feet	*Inches*					*Percent*	*Inches*			*Inches*	*Inches*		
1	7.5	1.0	12	L	3	1								
2	9.3	1.8	19	L	2	1					9.2	2.1	X	
3	8.7	1.4	15	D	7	1								
4	12.9	3.4	11	L	1	1	60	3.3	X					
5	10.1	3.0	20	L	2	0					31.2	1.8		X
:														
100	9.7	2.5	15	L	1	1					7.5	2.6	X	

[1] L = alive; D = dead.
[2] E = excisable; NE = nonexcisable.
[3] P = prunable; NP = nonprunable.

Five- to Ten-Year-Old Stands

Of major interest in 5- to 10-year-old stands are percentage lethally infected and percentage savable by pruning. Excision will not be possible in trees this small, so stem canker measurement is unnecessary. Trees with stem cankers or branch cankers within 6 inches of the stem are expected to die within 5 years. In addition, all trees with branch cankers between 6 and 24 inches from the stem have high probabilities of dying within 20 years unless those savable through pruning are pruned.

If heavy infection in one year threatens to cause unacceptably high mortality, and if sufficient reduction in mortality is possible through pruning, it may be economically feasible to prune. The value of the white pine component will largely determine the potential benefits of pruning at a young age. *Ribes* reduction may be desirable to prevent recurrence of high levels of lethal infection, or a second pruning may become necessary in a few years.

Mortality prediction for this age class of trees considers both current lethal infection rates and expected new lethal infection rates.

The sample includes 50 to 100 white pines 5 to 10 years of age. Recorded are condition of each tree (live or dead) and the category, (nonlethal-canker >24 inches from stem, prunable-6 to 24 inches from stem, or nonprunable-6 inches from stem or present in stem) of the most lethal canker. Table 5 illustrates a suggested data collection format. If pruning is not considered a treatment alternative, the trees can be recorded as infected or noninfected without regard to position of cankers. Fixed $^1/_{300}$-acre plots on a grid providing even coverage of the stand are recommended for sample tree selection.

Table 5—Rust status data format for 5- to 10-year-old stands

		Most lethal canker[2]		
Tree No.	Condition[1]	<6 inches or stem	6 to 24 inches	>24 inches
1	L		X	
2	L		X	
3	D	X		
4	L			X
⋮				
100	L		X	

[1]L = alive; D = dead.
[2]Distance from nearest margin of branch canker to stem.

APPENDIX E: PRUNING AND EXCISING

Pruning

Numerous guides for pruning white pines to control blister rust have been published over the years. Most of these were developed specifically for eastern white pine in the Lake States (Brown 1972; Nicholls and Anderson 1977). More recently, Hunt (1982) has developed guidelines for pruning western white pine in British Columbia, Canada. Recommended procedures have varied from single to double and even biennial pruning, and beginning in trees as small as 1 foot in height (Weber 1964).

Basal and lower stem cankers are most often the cause of mortality of blister rust-killed western white pines. These infections occur when trees are small, generally 2 to 5 feet in height. In trees this size, the lethal infection zone (fig. 4A) includes branches on the lower bole.

If stands are to be pruned only once, trees should be at least 10 to 20 years old, which allows selection of the best crop trees. Specific timing of pruning projects depends largely on the position of potentially fatal branch cankers. Decisions to prune or excise should always be preceded by a rust status survey (appendix D) to ascertain the proportions of trees uninfected, prunable, excisable, and untreatable in the stand.

A single pruning to a height of 8 feet or the lower 50 percent of the tree height (whichever is less) is recommended for Northern Region western white pine. This procedure should be accompanied by pathological pruning (removal of cankered branches only) of any infected branches within reach above the standard pruning height. Pruning branches to a set height has been shown to be more effective and, in some cases, less costly than pruning only infected branches (Stewart 1957). In pathological pruning, time is spent searching branches for infection, and still many cankers go undetected. Experience has shown that about 20 percent of the single-pruned trees will still be fatally infected (Stewart 1957). This figure may be reduced somewhat through excision at the time of pruning. But most of this mortality is due to infections that had been judged prunable but in fact were not prunable. You should expect about 20 percent fewer white pine to reach rotation than have been treated.

Where stocking is marginal, double pruning may be justified. Hunt (1982) offered recommendations for forests in British Columbia. He suggested a first pruning when trees are 8 feet tall, pruning to a height of 4 feet, with pathological pruning of higher infections. A second pruning would be carried out when trees were 13 feet tall, pruning to 8 feet, with pathological pruning above this height. A larger proportion of trees can be saved in the earlier pruning; however, new infections may threaten your investment unless they are removed in a second pruning or hazard is reduced through *Ribes* suppression.

Only white pines and all white pine crop trees should be pruned whether they appear to be infected or not. If excision is not part of the treatment, pines with only prunable cankers should be pruned, those with no stem cankers or nonprunable branch cankers. If excision is planned as well, all cankers should be prunable or excisable on selected trees.

Pruning to 8 feet can be accomplished using pruning shears with handles 2 feet long. Pole pruners may also be used to remove infections higher in the crowns; however, they are generally slower and more difficult to maneuver. They may add significantly to costs.

Live branches of the basal whorl often are partially buried in duff and vegetation and may be overlooked. Crews should be instructed to check carefully for basal branches.

Branches should be cut flush with the branch collar (fig. 6). White pine has very little tendency to develop decay from wounds, so wound treatment is not recommended.

Excising

Canker excision consists of cutting away all diseased bark and cambium or cutting a channel to the sapwood between diseased and healthy tissue (fig. 4D). This is best accomplished from mid-April through early June when cankers (fig. 4C) are most visible and bark slips easily while cutting. Excisable cankers are those that girdle no more than 50 percent of the circumference and with the upper edge of infection no more than 6 feet from the ground. This includes the discolored area beyond the obvious edge of the canker (figs. 4E and 4F).

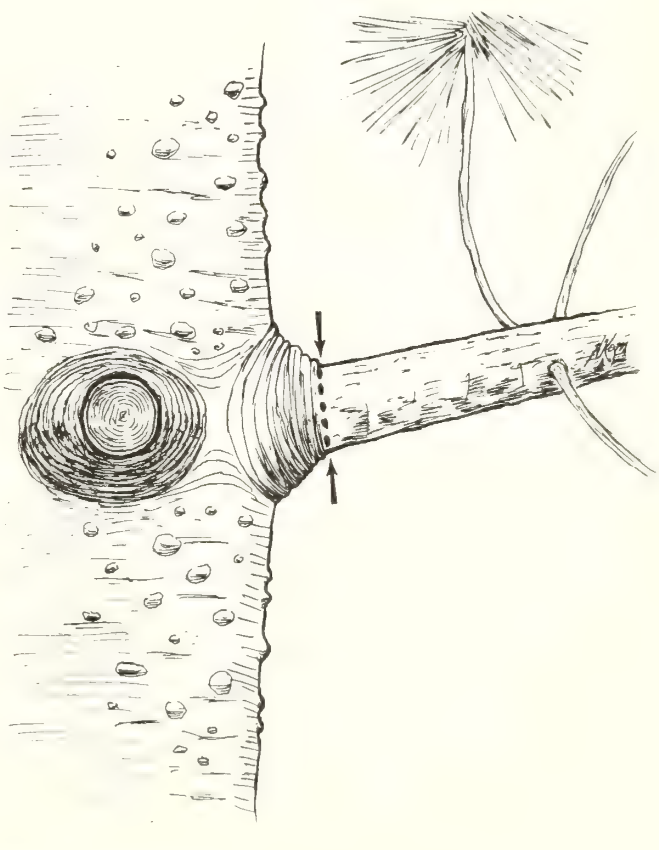

Figure 6—Branches should be pruned flush with the branch collar (arrows).

Branch cankers within 6 inches of the bole are removed by pruning the branch, followed by excising the bole around the branch collar 2 inches from the outer edge of the collar.

We recommend using a tree scribe with a ½-inch blade (fig. 4D). The inner edge of the channel should be 2 inches from visible discoloration. The channel must be scribed continuously all the way around the canker and fully to the sapwood. Cambial "bridges" may allow passage of the fungus beyond the groove. Basal cankers, which are those with the lowest edge less than 3 inches above ground (fig. 4B), are considered nonexcisable because of difficulties in performing the excision. This does not mean it cannot be done, but it would add unreasonable expense to treat such trees.

Excision should be preceded by pruning to standard height or one-half tree height. Trees with more than one stem canker should not be considered for excising.

Even for an inexperienced person, it should take less than a minute to complete the excision of a canker.

Additional Tips

Specific design of pruning and excising projects will vary by Districts and by situations. Choose the one most expedient for your project. Consider these tips: (1) If you are having difficulty detecting the leading edge of diseased tissue, try wetting the bark with water in a spray bottle. (2) Crop trees should be selected and marked before crews begin pruning and excising. (3) Both pruning and excising should be performed at one time by one person before moving on to the next tree. This saves repeating the inspection process to find stem cankers.

Costs

Few reports of pruning time and costs are available from western white pine experience. Foiles (1956) reported length of time required for pruning white pines to 17 feet using hand and pole saws. An average of one person-day was required to prune 128 trees to an average of 9.11 feet using handsaws. Pruning time for pole saws was considerably higher. These data included administrative time for supervision and marking as well as total crew time involving travel between trees, rest periods, and other delays.

Kelly Creek Ranger District, Clearwater National Forest, completed a pilot test of pruning and excising in 1983. They treated 86 trees/person-day by pruning or pruning and excising. The trees averaged 8 feet in height and were pruned to one-half their height. They treated 69 trees/acre for a cost of $63.36/acre or $0.92/tree. Costs included wages, transportation, tools, and miscellaneous administrative costs. The crews used pruning shears with handles 2 feet long for pruning and tree scribes for excising.

A pruning and excision project was completed in 1985 by the Palouse Ranger District of the Clearwater National Forest (Hagle and Grasham 1988). White pine plantations 15 to 18 years old were treated. Treated trees averaged 4.3 inches d.b.h. and 15 feet in height. They were pruned to one-half their height, with additional pathological pruning. Excision of a canker was required in 37 percent of the pruned trees. Eighty-eight acres, averaging 103 treated trees per acre, were treated at a cost of $56.82/acre. This cost included supplies, travel, wages, and benefits. The project required 45 person-days (0.51 person-day/acre) to complete. Nearly half of this time was in travel to and from the job. In terms of actual time on the job (excluding travel and training time), 2 person-hours were required to treat each acre.

APPENDIX F: SEED SOURCES

Planting stock recommendations are based on tested survival rates for the various progeny types now available. Phenotypically resistant trees from natural stands with high average infection rates were first selected (Phase I) and tested in 1950-57. New selections and tests were made again in 1967 (Phase II) and continue through the present. The percentage of offspring that survived artificial inoculation after 2 years was determined for each of these parents. Parent trees that had produced higher than average percentage of resistant progeny were considered to have general combining ability (GCA) (Steinhoff 1971). Those with lower than average resistant progeny were considered not to have general combining ability and were designated nonGCA. Various crosses with surviving progenies of the F_1 generation were made through controlled and open pollination (OP) (table 6). Progenies from these crosses were field tested and relative infection rates were measured.

Greatest resistance is obtained from the F_2 progeny (Bingham and others 1973) (table 6). These should be reserved for sites requiring the highest level of resistance for plantation success. F_1 x GCA parent backcross has a comparable overall number of infections in stands but a higher percentage of trees will be infected than will those of the F_2 stock.

F_1 and GCA x nonGCA stock have considerably less resistance than the previous two types but will have reasonably good survival rates on moderate hazard sites. GCA OP falls about midway between the F_1 or GCA x nonGCA and nonGCA OP. NonGCA OP is about the same as open-pollinated, phenotypically resistant, untested trees found in heavily infected stands.

Differences in infection rates between wild seedlings (those of unknown parentage), and progeny of phenotypically resistant, untested trees is minimal except in lowest hazard sites. Here, the progeny of phenotypically resistant trees show better survival.

Phenotypically resistant trees that have been tested in Phases I and II of the white pine tree improvement program (Franc 1982) should be used as operational seed sources by districts. These will provide GCA OP and nonGCA OP seed (table 7). Most white pine-producing Districts will have many trees that were tested among the first 400 screened in Phase I of the program. Many of these trees are the ortets for the grafted white pine seed orchard in Sandpoint, which now produces F_1 seed.

Table 6—Derivation of recommended stock types

Designation	Derivation
Wild	Generally from natural regeneration where seed tree selection was not made.
Phenotypically OP	Selected seed trees or seed collected from selected naturally grown trees.
NonGCA OP	Open pollinated seed from trees known not to have general combining ability.
GCA OP	Open pollinated seed from trees known to have general combining ability.
GCA x nonGCA (Not available)[1]	Controlled pollinated seed from trees known to have general combining ability crossed with trees known not to have general combining ability.
F_1	Controlled pollinated seed from cross between two trees known to have general combining ability.
F_1 x GCA parent (Not available)[1]	Controlled pollinated seed from backcross between F_1 and GCA parent.
F_2	Controlled pollinated seed from cross between two or self of one, F_1 trees.

[1]Seed from these sources has been tested but is not generally available for operational use because the crosses are made through controlled pollination.

Table 7—Genetic makeup of current seed sources covered in USDA Forest Service Northern Region Handbook (USDA FS 1984)

Seed source	Genetic makeup
Seed collection stand[1]	Wild type
Selected individual tree	Wild type, Phenotypically resistant
Seed production area[2]	Wild type, Phenotypically resistant
Test plantation[3]	Mixed: approximately equivalent to F_1
Progeny tested wild trees	NonGCA x OP, GCA x OP
Seed orchard	F_1 - Sandpoint Seed Orchard
	F_2 - Moscow Arboretum, Coeur d'Alene Seed Orchard, Lone Mountain Seed Orchard

[1]Not an approved seed source for USDA Forest Service, Northern Region.

[2]Seed production areas that do not qualify for selection of phenotypically resistant parent trees—stand has not experienced 80 to 90 percent mortality of western white pine due to blister rust—should be considered to produce wild-type seed. Phase II plus trees that have not been progeny tested are considered to be phenotypically resistant seed sources.

[3]USDA Forest Service test plantations consist of a variety of stock types ranging from wild-type (control) to F_2 (Moscow Arboretum seed). Progeny tests from these seed mixtures have shown the test plantations to produce approximately equivalent resistance to F_1 stock from the Sandpoint Seed Orchard. Approved plantations are Canyon Creek on the Priest River Experimental Forest, Fernwood and Merry Creek on the Idaho Panhandle National Forests (St. Maries Ranger District), and Elk River and Hog Meadows on the Clearwater National Forest (Palouse Ranger District).

APPENDIX G: *RIBES* ECOLOGY AND MANAGEMENT

Ribes viscosissimum, and *R. lacustre* are the *Ribes* species of greatest concern to white pine managers in the Northern Region. They are "upland" species, dispersed throughout white pine stands, as compared to those limited to creek bottoms or other wet areas. Together they constituted 93 percent of the *Ribes* plants eradicated in this Region from 1923 through 1950 (Moss and Wellner 1953). Their site requirements correspond well to those of western white pine (appendix A). Both *Ribes* species survive and reproduce best on moderately cool, moist, north and east exposures. Both also will grow on warmer, drier slopes, although *R. viscosissimum* does better than *R. lacustre* on these sites. *Ribes viscosissimum* is most abundant in stands with western larch, lodgepole pine, Douglas-fir, Engelmann spruce, subalpine fir, and white pine. It is more readily suppressed by competition for sunlight in stands with major components of grand fir, western hemlock, and western redcedar. *Ribes lacustre* survives better than *R. viscosissimum* in stands of the latter type because of its greater shade tolerance. *Ribes lacustre* requires only 25 percent of full sunlight as compared to 40 percent for *R. viscosissimum.*

Ribes seed production begins at 3 to 5 years of age and continues annually as long as the plant survives. *Ribes lacustre* is also capable of reproducing by layering. Seeds from *Ribes* plants are heavy, and dispersion from the mother plant is limited. If undisturbed, viable seed remains stored in duff for more than 200 years. Cool, moist duff commonly found under the closed canopy of a mature forest provides ideal storage conditions for prolonged *Ribes* seed viability. Exposure of mineral soil by fire or by mechanical disturbance of the duff will stimulate *Ribes* seed germination. Incomplete exposure of the mineral soil can stimulate germination, but survival of germlings is low if a partial duff layer is still present.

Management

Silvicultural Control—Controlling light regimes to regulate *Ribes* populations can be a consideration in commercial stands. Moderate cutting that permits 30 to 50 percent of full sunlight to the ground can be effective in reducing rust hazard through *Ribes* suppression. Following logging, an average of 200 *Ribes* seeds per acre can be expected to germinate, and about 20 seedlings may become established (Moss and Wellner 1953). These figures vary considerably among sites, depending on site histories. Most of the young *Ribes* plants will receive insufficient sunlight for survival under the forest canopy, and within a few years following thinning they will have died. Most of the residual, ungerminated seed is devitalized by increasing temperature and decreasing moisture in the duff. Surviving bushes will be localized in openings such as logging roads or slash-burning areas. When the remainder of the stand is harvested, the *Ribes* population—rust hazard—should be much reduced compared to the potential hazard prior to cutting.

Increasing solar radiation enough to devitalize stored *Ribes* seed but not enough for prolonged support of *Ribes* plants requires considerable planning and control. Wellner (1948) found that 30 to 40 percent of the basal area in a well-stocked, mature stand can be removed to achieve the required light regime (30 to 50 percent of full sunlight). If canopies are not sufficiently opened, only a small proporton of the stored *Ribes* seed is devitalized. Few *Ribes* from seeds that germinate following stocking reduction of less than 30 percent of the basal area of well-stocked, mature stands survive to become established. Therefore, such cuttings neither increase nor greatly decrease site rust hazard.

Stocking reductions that remove more than 40 percent of the volume from well-stocked, mature stands may provide ideal conditions for *Ribes* reproduction. Light shading improves *Ribes* seedling survival and seed storage conditions. Moss and Wellner (1953) reported an average of 1,542 *Ribes* seeds per acre germinating in 12 such heavily cut stands. Of these germlings, 1,472 survived to become established.

Moderate intensity, high or selection thinnings in commercial stands, and some applications of shelterwood regeneration methods provide opportunities for rust hazard reduction. Refer to appendix C for a discussion of stocking reduction in white pine stands.

A preparatory shelterwood cut that reduces basal area by 30 to 40 percent can reduce rust hazard. At least 5 years should be allowed between this and the next cut, generally a seed cut, to allow time for seed devitalization and shading death of germinated *Ribes* plants.

Minimizing duff disturbance during harvest can greatly reduce *Ribes* seed germination. Winter logging has resulted in 95 percent fewer *Ribes* seedlings than summer logging (Moss and Wellner 1953). Most ungerminated seeds will devitalize within about 3 years because storage conditions are changed by raising temperature and decreasing moisture in the duff. If slash is piled and burned before *Ribes* seed devitalization occurs, seed will germinate along the periphery of burn sites. Full sun produces the most rapid devitalization. Increasing shade prolongs the period of seed viability. Under full shade, as occurs with light stocking reductions, seed viability can be extended up to 25 years.

Direct Control

Total elimination of *Ribes* should not be attempted; instead, aim to reduce the population to levels that suit resistant white pine stock types available.

Ribes bushes are most effectively eradicated by means of a claw mattock developed for this purpose. The root crown and about 4 inches of root below the crown must be removed to assure the plant will not resprout. This method is not totally effective due to frequent resprouting of improperly pulled plants and crews missing plants (USDA FS 1959a).

More efficient is chemical control of *Ribes* (Offord and others 1958). Spot spraying using backpack sprayers is best suited to sites with clumped *Ribes* distribution. Miller (1984) was able to kill as much as 89 percent of established 2-year-old *R. viscosissimum* plants on a white pine site applying chemicals from a backpack sprayer. Broadcast spraying, generally from helicopters, will be more efficient where *Ribes* populations are heavy and disperse (DeJarnette 1953). Efficiency of chemical control varies with the compound used and application rate (Miller 1984; Miller and Kidd 1983), physiological conditions of *Ribes* (Miller 1984), weather and site factors, and method of application. Assistance of a qualified pesticide applicator is necessary for any spray project.

APPENDIX H: *RIBES* POPULATION DETERMINATION

Ribes population surveys are generally conducted to determine the white pine type appropriate for regeneration or the need for *Ribes* population reduction. Among conditions where *Ribes* surveys may be desirable are (1) clearcut or burned areas that have had sufficient time for *Ribes* to become established (3 years) and are intended for white pine regeneration; (2) young plantations or natural stands that have sufficiently high infection rates to indicate a need to reduce *Ribes* populations; (3) open stands where natural openings, tree mortality, or partial cutting have resulted in conditions favorable for *Ribes* and white pine is considered for regeneration.

Knowledge of exact *Ribes* populations is not necessary. Five *Ribes* population levels are used to determine relative rust hazards (table 3).

Ribes Identification

Hitchcock and Cronquist (1976) list 30 species of *Ribes* in the Pacific Northwest. The upland species are the most uniformly distributed and thus are considered most important for *Ribes* population determination species in the white pine type. In northern Idaho and western Montana, *R. viscosissimum* and *R. lacustre* are the most common of the upland species.

Ribes plants have simple leaves as compared to the compound leaves of rose (*Rosa* spp.), or raspberry (*Rubus* spp.) (fig. 5B, center of book).

Ribes can be confused with thimbleberry (*Rubus parviflorus*) and ninebark (*Physocarpus malvaceous*). The latter two species have stipules at the junction of the petiole and stem; *Ribes* species have no stipules.

Ribes lacustre (fig. 5C) (prickly currant) has shiny green leaves with well-divided lobes. Stems are brown with many spines or prickles, particularly at nodes.

Ribes viscosissimum (fig. 5D) (sticky currant) has pubescent, glandular (sticky) leaves, which have a spicy odor when crushed. Lobes of leaves are broad, rounded. Stems are spineless.

Survey Methods

Ribes populations generally peak 3 or 4 years following site disturbance. Bushes are larger and easier to detect 4 to 10 years after site disturbance. Small *Ribes* plants are easily missed, especially where populations are low.

Ribes population determinations can be incorporated into stand examinations by counting *Ribes* plants that fall, in any part, within the fixed-radius plot. Plots $^{1}/_{100}$-acre (11.9-foot-radius circular plots) or $^{1}/_{300}$-acre (6.8-foot-radius circular plots) in size may be used to tally *Ribes* bushes during stand examinations.

Plots should be on a grid covering the stand evenly. If plots are established at 5-chain intervals along a compass line with 10-chain intervals between parallel lines (USDA FS 1985), $^{1}/_{100}$- and $^{1}/_{300}$-acre plots give about 2 percent and 1 percent coverage, respectively.

If the *Ribes* survey is not conducted in conjunction with stand examination, a continuous strip method may be used (USDA FS 1959b). A 16-foot-wide continuous strip is run along a compass line. All *Ribes* plants encountered in a 1-chain interval along the strip are tallied. We recommend maintaining a map of strips. This will aid in identifying higher risk areas within a stand where *Ribes* distribution is clumpy.

Strip interval is 4, 8, or 16 chains depending on density and distribution of *Ribes*. Intervals of 16 chains may be sufficient for large units with large, evenly distributed *Ribes* populations. The entire stand should be covered first in 16-chain intervals. Lengths of strips are measured by pacing. One acre is equal to a 16-foot-wide, 41.25-chain-long strip. If *Ribes* plants are infrequent in the initial survey, go back and fill in by offsetting 8 chains and running an additional strip between each of the first strips. Intervals of 4 chains may be used where stands have very few *Ribes* plants or highly clumped distribution of *Ribes*. Intervals of 16, 8, and 4 chains give about 2, 3, and 5 percent coverage, respectively.

Potential *Ribes* Population Estimates

Estimating potential *Ribes* populations for uncut sites is less definitive than surveying existing populations and requires interpretation of many factors. Moss and Wellner (1953) set forth guidelines to aid in estimating potential *Ribes* populations for uncut sites. Their guidelines are presented below. These can be used to separate two general ranges of *Ribes* populations—low and high. Sites judged to have low *Ribes* potential by this method are considered equal to rust hazard level 2. Based on results of *Ribes* surveys conducted from 1932 to 1966, (published in annual reports of the blister rust control program of the Northern Service Region of the Forest Service) sites with high *Ribes* potential should be considered to have rust hazard level 5 if located in the St. Joe or Clearwater areas of Idaho, and level 4 outside these areas. Although these broad categories are less than satisfactory, they are better than having no rust hazard estimate for selecting appropriate white pine planting stock.

Guidelines from Moss and Wellner (1953) are as follows:

Populations Averaging Less Than 25 Bushes Per Acre (Rust Hazard Level 2)

1. Stands on south and west slopes that originated after two or more fires occurring less than 20 years apart.

2. Stands that originated after two or more fires which together completely consumed the organic mantle down to the mineral soil.

3. Stands overmature, more than 200 years old, fully stocked since inception, and composed largely of western hemlock and western redcedar.

4. Stands with a high proportion of western larch, lodgepole pine, ponderosa pine, and Douglas-fir growing in shallow soil with a substratum of sand, gravel, or rock.

Populations Averaging More Than 25 Bushes Per Acre (Rust Hazard Level 4 or 5)

1. Stands that originated after a single burn.

2. Stands on north and east exposures that originated after two or more natural fires occurring more than 10 years apart.

3. Stands that originated after one or more fires, none of which completely consumed the organic mantle down to the mineral soil.

4. Open-grown stands on north and east exposures with inadequate cover to suppress *Ribes* bushes or prevent their continued seeding.

5. Crests of prominent ridges from which *Ribes* bushes are rarely suppressed by forest cover.

6. Heads of drainages where streams finger out over upland slopes and create habitats more favorable for shrubs than for trees.

These guidelines can be enhanced for white pine stock type selection by integrating observations of *Ribes* populations from surrounding sites with similar histories, or from road cuts, open ridgetops, or other features which prolong upland *Ribes* survival.

Surveys of *Ribes* seeds in forest soil and duff may be of considerable utility in estimating potential (Quick 1956). But techniques have not been developed sufficiently for operational use.

Hagle, Susan K.; McDonald, Geral I.; Norby, Eugene A. 1989. White pine blister rust in northern Idaho and western Montana: alternatives for integrated management. Gen. Tech. Rep. INT-261. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 35 p.

This report comprises a handbook for managing western white pine in northern Idaho and western Montana, under the threat of white pine blister rust. Various sections cover the history of the disease and efforts to combat it, the ecology of the white pine and *Ribes*, alternate host of the rust, and techniques for evaluating the rust hazard and attenuating it. The authors advocate an integrated control strategy based on local stand conditions. Options include planting resistant strains of pine, excising cankers, and chemical, mechanical, and silvicultural control of *Ribes*.

KEYWORDS: silviculture, timber management, plant pathology, *Ribes* spp., forest genetics, reforestation, *Pinus monticola*

PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

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United States
Department
of Agriculture

Forest Service

**Intermountain
Research Station**

General Technical
Report INT-262

May 1989

Proceedings—Symposium on the Management of Lodgepole Pine to Minimize Losses to the Mountain Pine Beetle

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COVER PHOTO: Creation of a mosaic of age and size classes, and species diversity, is one of the best long-term strategies for minimizing lodgepole pine losses to the mountain pine beetle.

Proceedings—Symposium on the Management of Lodgepole Pine to Minimize Losses to the Mountain Pine Beetle

Kalispell, MT, July 12-14, 1988

CANADA-UNITED STATES
MOUNTAIN PINE BEETLE-LODGEPOLE PINE PROGRAM

Compiler:

GENE D. AMMAN, Principal Entomologist, Intermountain Research Station, Ogden, UT

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FOREWORD

Recent progress in management strategies to mitigate impacts of mountain pine beetle infestations prompted this symposium. Significant progress has been made in the areas of hazard-rating stands for beetle infestations, and silvicultural, chemical, and pheromone methods of reducing infestations and protecting trees.

This symposium was a success because of the whole-hearted cooperation of speakers, moderators, participants, and support staff. The following deserve special recognition:

Program Chairman: Dave Holland, Group Leader, Forest Pest Management, State and Private Forestry, Intermountain Region, Forest Service, Ogden, UT.

Local Arrangements: Jed Dewey, Entomology Group Leader, Cooperative Forestry and Pest Management, Northern Region, Forest Service, Missoula, MT; Jim VanDenburg, Forest Silviculturist, Flathead National Forest, Kalispell, MT.

Field Trips: Ken Gibson, Entomologist, Cooperative Forestry and Pest Management, Northern Region, Forest Service, Missoula, MT; Barry Bollenbacher, Silviculturist, Flathead National Forest, Big Fork, MT.

Gene D. Amman
Proceedings Compiler

CONTENTS

CANADA/U.S. MOUNTAIN PINE BEETLE/LODGEPOLE PINE PROGRAM 1981-1988

David A. Graham and Gordon Miller

ABSTRACT: Concerns over widespread mountain pine beetle outbreaks in the 1970's and early 1980's motivated the Forest Service, U.S. Department of Agriculture, and the Canadian Forestry Service to initiate a joint program to mitigate lodgepole pine losses caused by the insect. Since 1981, cooperative work in the program has resulted in many accomplishments. Although hampered by funding problems, program chairmen from the two Nations expect additional progress in the future.

BACKGROUND

Mountain pine beetle outbreaks have occurred rather frequently in both the western United States and western Canada throughout recorded history. Some have been rather localized, others have covered vast acreages often followed by catastrophic wild fires, mostly in the United States. During the 1970's, severe outbreaks began to develop in a number of areas in the State of Montana, including Glacier and Yellowstone National Parks. By 1980, some 4 million acres in Montana were severely affected by the mountain pine beetle. During the late 1970's, outbreaks were beginning to occur in both increasing numbers and size in Canada--especially in British Columbia and just north of the Canada/U.S. border in Waterton Lakes National Park, Alberta, and adjacent areas. Widespread tree-killing resulted in increasing media and political attention during 1979, 1980, and 1981. A number of Canadians were expressing considerable concern over "the lack of aggressive control action in the United States," particularly in Glacier National Park and in the North Fork of the Flathead River.

Two key forestry coordination and information exchange meetings between U.S. Forest Service and Canadian Forestry Service officials that brought this subject up for possible resolution were held in Washington, DC, on November 4, 1980, and in Ottawa, Canada, on June 22-23, 1981. A followup meeting was also held in Victoria, Canada, on February 15, 1982, in conjunction with the North American Forestry Conference. U.S. Forest Service Chief Max Peterson, Assistant Deputy Minister (ADM) for the Canadian Forestry Service Les Reed, and key members of their staffs were in attendance at all of these meetings. The concern and need for action expressed by the two countries over the mountain beetle situation was recorded in the minutes of the 1981 Ottawa meeting as follows:

> The Mountain Pine Beetle Program. The Mountain Pine Beetle problem in Western Canada is becoming acute as the beetle moves from the United States to Canada along the Rocky Mountains in both British Columbia and Alberta. It is a problem that is gaining a great deal of political visibility in Canada, even as it did earlier in the United States. The ADM and Chief agreed that there were opportunities here for important joint collaboration between the two countries, perhaps similar to the work already done under CANUSA (Canada/U.S. Spruce Budworm Program). Several points came up as follows:
>
> a. That the R&D review now being performed by the USFS (in cooperation with Canada) would be completed in about a month and this would serve as a point of departure not only for R&D work, but for application and full-scale operational work as well.
>
> b. The two countries could convene a state-of-the-art review in perhaps 3 months in Canada or the United States. In any event, this review of the state-of-the-art would involve political and land management leaders of both countries and would serve as a departure point for the next step in collaboration.
>
> c. There would be no objections to a CANUSA-like program; however, we would draw on improving the operating procedures of the CANUSA program if a Mountain Pine Beetle program were launched.
>
> d. Chief Peterson is to write a letter to ADM Reed outlining how we see the next steps in initiating a joint program on the mountain pine beetle.
>
> e. We would try to bring mountain pine beetle work under a blanket overall agreement between the two countries--the mountain pine

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Presented at the Symposium on the Management of Lodgepole Pine to Minimize Losses to Mountain Pine Beetle, Kalispell, Montana, July 12-14, 1988.

David A. Graham is Director of State and Private Forestry, Intermountain Region, USDA-Forest Service, Ogden, Utah. Gordon Miller is Program Director, Forest Protection Research, Canadian Forestry Service, Pacific Forestry Centre, Victoria, British Columbia, Canada. They are Co-chairmen of the Canada/U.S. Mountain Pine Beetle Program for the two respective countries.

beetle agreement being the first amendment under such an overall accord. A proposed mountain beetle US/Canadian agreement was given to Brandt and Anderson.

Thus, it was agreed at the Ottawa meeting that efforts to mitigate mountain pine beetle-caused losses to lodgepole pine and related resources could be enhanced and made more effective by improving inter-country coordinating mechanisms, and through more wide-spread sharing of knowledge and scientific talent. The letter from Chief Peterson to ADM Reed, outlining the process for initiating a joint program was transmitted to Canada on August 25, 1981.

The letter stressed the immediate need to aggressively implement salvage and fire hazard reduction programs, to increase thinning of younger lodgepole pine stands, and to improve utilization of the species. The emphasis focused on improving the economic situation and providing better access to and within the many unroaded forested areas. The letter included a proposed Memorandum of Understanding (MOU) covering specific mountain pine beetle/lodgepole pine management cooperation needs and accomplishment authorities. This MOU became a supplement to an overall MOU between Canada and the United States covering the entire field of forestry. These documents, covering a 5-year period, were approved by both countries during June 1982. The supplemental MOU on mountain pine beetle, was also signed by all border States and Provinces involved (Washington, Idaho, Montana, British Columbia, and Alberta). This later document has now become a "Project Agreement" supplementing the overall forestry cooperation MOU. Both documents were recently approved by both countries for another 5-year period.

ACTIVITIES

The first step of the original initiative was a "state-of-the-art" meeting which was held at Fairmont Hot Springs, British Columbia, on November 3-4, 1981. This included a very informative field trip demonstrating Canadian control efforts and considerable press coverage. A complete proceedings was published by the Canadian Forestry Service: "Proceedings of the Joint Canada/U.S.A. Workshop on Mountain Pine Beetle Related Problems in Western North America (BC-X-230), 1982." The approximately 70 participants included State Governor and Provincial government representatives as well as all concerned land management agencies and private industry. To provide continuity and to facilitate the overall implementation and coordination of this program, a joint Canada/U.S. Lodgepole Pine/Mountain Pine Beetle Steering Committee was established by the two involved Federal governments. Co-chairmen appointed were Dave Graham (U.S.) and Ross Macdonald (Canada). Other members included Jack Thompson (U.S. Field Coordinator), Max McFadden (U.S. Research Representative), and Tom Sterner (Canadian Coordinator and Research Representative). The current co-chairmen are Gordon Miller (Canada) and Dave Graham (U.S.). The U.S. "Field Coordinator" position has been replaced by the Local Border Lodgepole Pine Management Coordination Group, currently chaired by John Hughes, USDA Forest Service, Missoula, Montana. The current U.S. Research Representative is Garland Mason, USDA Forest Service, Washington, DC.

As part of the followup to the Fairmont Hot Springs meeting, a joint Canada/U.S. "Executive Summary" of the situation was prepared and furnished to all participants as well as to all key forestry and political leaders. This 15-page document also included statistical and map appendix information showing recent infestation trends and current status by major political subdivisions, and an Action Plan developed in final form during a joint Canada/U.S. October 1982 meeting in Victoria, BC. This Action Plan provided the basis for carrying out a number of specific program goals and objectives in both countries.

One of the major outcomes of the Fairmont Hot Springs meeting was a general consensus that a major accelerated research effort (similar to the Canusa Spruce Budworm Program) was not needed, although some significant research needs were identified. The most urgent program needs identified were: (1) to get agreement on what is really known about the mountain pine beetle and its interactions with lodgepole pine, and (2) to aggressively implement that knowledge in such a way so as to significantly reduce current and future losses in a timely manner.

This was all done in full realization that additional funding would probably not be forthcoming. However, part of the rationale behind the development of the Executive Summary was to provide all key decision makers with enough of the most significant information so that rearranging of current and future funding priorities could be considered. In the U.S., copies went to key congressional members, Senate Committee on Agriculture, House Committee on Interior and Insular Affairs, and both appropriation committees. Similar contacts were made with Cabinet Members in Canada. Except for some polite acknowledgments, there was no significant positive Federal response to the funding needs identified. However, control activities were eventually accelerated considerably, particularly in Alberta and British Columbia.

During the development of the Executive Summary, a number of meetings involving most of the key mountain pine beetle/lodgepole pine scientists in both countries were held. One of these, held in Bend, Oregon, on September 20-24, 1982, included a field trip to view demonstration areas showing dramatic differences in the severity of mountain pine beetle tree-killing between thinned and unthinned stands, many of which were mature (120 years plus). During this meeting, considerable effort was also spent jointly developing a "Statement of Facts" that attempted to more clearly define the "state-of-the-art," and management practices that could be currently

recommended to reduce mountain pine beetle losses. Copies of this document, which was subsequently refined in the U.S. through further exchanges with all scientists and practitioners involved, were circulated to all lodgepole pine area managers and practitioners.

Several meetings were also held during this same general time period to develop specific tasks and further refine responsibilities for accomplishing each Action Plan Item. The wrap-up Canada/U.S. work plan agreement meeting was held in Portland, Oregon, April 19-22, 1983.

Final approved work plans, including specific tasks and assignments, were provided on June 23, 1983, to all responsible units in the U.S. and shortly thereafter in Canada. One of the identified tasks was to develop periodic accomplishment reports showing progress and highlighting future needs. The first of these, which included a complete primary mountain pine beetle contact list and progress through 1983, was distributed in 1984. Progress Report No. 2, adding 1984 accomplishments, was distributed in 1985.

Much has been accomplished--most of it without additional funding. Accomplishments to date are summarized very well in the two Progress Reports and in the 1987 revised Work Plan.

PROGRAM REVIEW

A complete review of the program was carried out in 1985-1986. Each Action Plan Item, and the original tasks developed to accomplish each one, was reassessed in both countries in terms of progress made to date, current applicability, additional needs, and current funding requirements. The revised work plan was provided to all interested parties, including appropriate administrators and Congressional and Cabinet members in May 1987, as a revised "Canada/U.S. Mountain Pine Beetle Program/Work Plan--October 1986." The progress to date was noted in this revised Work Plan, and it serves as Progress Report No. 3. Separate progress reports covering 1985-1986 accomplishments were not published.

The Work Plan was recently revised again this year to update recent personnel changes, clarify some of the task assignments, and to reach agreement on priorities for whatever new funding may be made available. This latest revision was developed during a meeting with United States participants in Salt Lake City on December 3-4, 1987, and through a series of followup communcations with Canadian participants. Copies of this revision, which includes an up-date on accomplishments to date, were recently provided to all interested parties.

ACCOMPLISHMENTS

Program accomplishments to date highlight a broad spectrum of successful cooperative activities between Canadian and U.S. scientists and administrators. Some of the more significant accomplishments include:

1. Conducted Fairmont Hot Springs state-of-the-art meeting in Canada. Meeting initiated the development of a number of special coordination mechanisms and agreement on management strategies that could be immediately and effectively used to reduce future MPB resource damage.

2. Established a joint local border committee to ensure coordination and information exchange on MPB and lodgepole pine management among Canadian and U.S. resource managers with common administrative area boundaries.

3. Completed two up-to-date publications outlining recommended strategies for reducing resource losses under a variety of stand and MPB outbreak situations. For Canada: "Suppression of Mountain Pine Beetle in Lodgepole Pine Forests," McMullen et al, 1986. For U.S.: "Integrating Management Strategies for the Mountain Pine Beetle with Multiple Resource Management of Lodgepole Pine Forestry," McGregor and Cole, 1985 (replaces the 1977 INT General Technical Report-36).

4. Conducted Smithers, BC, May 1985 Symposium. A state-of-the-art meeting hosted by British Columbia Forest Service, Canada--somewhat similar to this symposium.

5. Published an inventory, description, and result highlights of existing MPB/LPP silvicultural studies and demonstration areas.

6. Developed INFORMS and expert system shell that employs artificial intelligence and integrates existing MPB/LPP data bases into a Geographic Information System (GIS).

7. Evaluated a number of lodgepole pine hazard rating systems to determine need and usefulness.

8. Coordinated the evaluation and registration of semiochemicals for manipulating mountain pine beetle populations in the U.S.

FUTURE

We believe this program will continue to receive top-level support in the years ahead in both countries. We plan to continue progress on this program with or without additional funding. We know the efforts being made, including the many innovative ways being used to accomplish most of the identified high-priority tasks without additional funding, are sincerely appreciated by those that appropriate and allocate resources. As additional progress is made in the future, we can expect increasing administrative and political recognition and support. This is truly a cooperative effort supported by a lot of dedicated people in both countries. We hope to build on this spirit of cooperation as we move ahead with this program in the future.

MOUNTAIN PINE BEETLE STATUS--WESTERN UNITED STATES

Kenneth E. Gibson

ABSTRACT: Though many MPB outbreaks are declining westwide, more than 2.5 million acres of host type were infested in 1987. Infestation levels and trends for each Region are noted.

INTRODUCTION

There are few superlatives which have not been used to describe the extent and magnitude of mountain pine beetle (MPB) infestations in the West during the last 20 years. New, in response to management activities and host depletion, many infestations Westwide have died out. Others are on the decline. Still, MPB is far and away the most devastating forest insect in western North America.

Though the focus of this symposium is on MPB effects in lodgepole pine (LPP), beetles regularly infest and kill nearly any pine species--both native and introduced--within their range. In our Region--western Montana and northern Idaho--serious infestations are occurring in ponderosa pine. Past outbreaks have killed hundreds of thousands of western white and whitebark pines as well.

The biology and ecology of MPB and its hosts will be discussed in great detail during the course of this symposium. Suffice it to say, in an introductory manner, that the beetle and its hosts have lived in mutualistic relationships for longer than we have been recording outbreaks. Mountain pine beetle, LPP and stand-replacing fires became a very efficient cycle which resulted in LPP becoming one of the most expansive forest types on the continent. About a century ago, however, land managers adopted a perhaps too successful fire suppression program, and a few decades hence, foresters were left to comtemplate literally millions of acres of dead LPP!

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Kenneth E. Gibson is an Entomologist, Timber, Cooperative Forestry and Pest Management, Northern Region, Forest Service, U.S. Department of Agriculture, Missoula, MT.

As I mentioned earlier, recorded MPB outbreaks go back as far as do records. It is widely believed that the journals of Lewis and Clark referring to downfall and dead timber were documenting the effects of MPB. More recently, Jim Evenden, early Forest Service entomologist, began surveying and recording MPB infestations throughout the Intermountain west in the 1920's. Localized outbreaks of varying degrees of severity were observed from then until the late 1960's. It was about then that our success in controlling fires began to be manifest in large expanses of mature to overmature LPP. Beginning in LPP stands in Yellowstone National Park and forests in Utah, Idaho, and Montana, the beetle's effect on stand structure over the past 20 years is well documented. In the area encompassed by the Forest Service's Northern Region--Montana, northern Idaho, and Yellowstone National Park--it is estimated that more than 250 million LPP have been killed in the last 20 years.

CURRENT STATUS AND ANTICIPATED TREND

At last, infestations in our Region--and for the most part other Regions as well--are declining. Still, in 1987, more than 2.5 million acres were infested westwide. The following is a Region-by-Region description of MPB outbreak status and the anticipated trend of those outbreaks in the foreseeable future.

<u>Northern Region (Montana, northern Idaho, Yellowstone National Park)</u>: The series of outbreaks which continued to build in our Region through the late 1970's reached their peak at more than 2.4 million acres in 1981. Since that time, though some Forests continue to harbor locally severe and occasionally increasing infestations, acres on which infested trees were observed have gradually declined. In 1987, the infested area was reduced to approximately 722,000 acres--which includes all species on all ownerships. That was significantly reduced from 943,000 acres in 1986. Infestations on the Bitterroot, Idaho Panhandle, Kootenai, Flathead, and Nez Perce National Forests are increasing in some localities. Regionwide, however, we expect a continued decreasing trend in 1988 and for the next several years.

<u>Rocky Mountain Region (eastern Wyoming, South Dakota, Colorado)</u>: In 1987, MPB infestations were recorded on more than 58,000 acres. Estimated mortality totalled almost 110,000 trees--approximately 30 percent were lodgepole pine, the remainder ponderosa pine. In Colorado,

MPB infestations in LPP peaked in 1982. As a result of the High Country Integrated Pest Management Project, suppression projects have reduced tree losses significantly in the past 5 years. Elsewhere in Colorado, beetle-caused mortality in ponderosa pine stands remains high, but is decreasing. Lodgepole pine stands in Wyoming continue to experience MPB-caused losses but at declining rates since 1984. A MPB outbreak in ponderosa pine near Laramie Peak is increasing. In South Dakota, infestations in the Black Hills are static at about 3,800 acres infested.

Southwest Region (Arizona, New Mexico): Historically, MPB has reached outbreak proportions at irregular intervals in ponderosa pine stands in northern portions of the Region. Infestations typically last 3 to 20 years with little recurrence in the same areas. At the present time, beetle activity is limited to scattered ponderosa pine stands on the Carson National Forest and adjacent Taos Pueblo Indian Reservation. Covering approximately 1,200 acres, the infestation could increase to 5,000 acres over the next 5 years. To date, some 1,800 trees have been killed.

Intermountain Region (western Wyoming, Utah, southern Idaho, Nevada): Tree mortality attributed to MPB decreased markedly in 1987. In 1986, an estimated 1.5 million trees had been killed. In 1987, that total did not exceed 200,000. Much of that reduction was due to the collapse of a once massive infestation in LPP and ponderosa pine stands in northeastern Utah. Static to slightly increasing infestations were noted in southern Idaho on the Boise, Challis, and Sawtooth National Forests. In total for the Region, infestations were recorded on 36,000 acres in southern Idaho, 97,400 acres in Utah, and another 2,300 acres in western Wyoming. Few of those infestations are expected to increase in 1988.

Pacific Southwest Region (California): Mountain pine beetle outbreaks in California have not been historically significant. However, locally important infestations occur from time to time. A small outbreak in ponderosa pine was recorded near Willits in 1987, and an infestation in LPP extended to 20,000 acres in Yosemite National Park. That outbreak, believed related to a lodgepole needleminer infestation, is expected to decline in 1988.

Pacific Northwest Region (Oregon, Washington): In numbers of acres infested, the Pacific Northwest Region contains the most expansive MPB outbreaks in the United States. In 1987, approximately 1.6 million acres were still infested--down from 1.76 million acres in 1986. Forests in Oregon continued to experience the most losses with more than 1 million cubic feet volume killed on 1.4 million acres on the Deschutes, Fremont, and Winema National Forests. In Washington, most losses occurred on the Okanogan National Forest. Infestations are expected to remain static in southcentral Oregon and increase in northcentral Washington in 1988.

The largest infestation in the Region--on the Deschutes National Forest--is moving from LPP stands to second-growth ponderosa pine.

CONCLUSION

In summary, though many areas are still experiencing serious MPB outbreaks--and associated impacts on several resources--we believe we are in the final stages of the last of the "great" MPB outbreaks. Perhaps through continued research, efficient technology transfer, and the economic and political climate needed to implement sound silvicultural practices, at the next MPB/LPP symposium we will be able to report that the beetle problem has been effectively dealt with.

STATUS OF MOUNTAIN PINE BEETLE IN WESTERN CANADA, 1988

G.A. Van Sickle

ABSTRACT: Although again at generally endemic levels in Alberta, mountain pine beetle continues to be a major forest pest in British Columbia. The extent of the present infestation is described along with trends, a forecast, and control programs.

INTRODUCTION

The mountain pine beetle continues, as it has for the past decade, to be the most damaging forest insect in British Columbia. Populations in southwestern Alberta and Saskatchewan have returned to endemic levels. Mature lodgepole pine are by far the most commonly killed tree species, followed by western white pine, occasionally ponderosa pine, and other pines. The distribution of currently active infestations in western Canada is shown in figure 1.

Lodgepole pine is distributed throughout British Columbia and adjacent Alberta. In British Columbia, it covers more than 14 million ha and by volume comprises 15% of the provincial inventory, although in some areas it is much higher, reaching 50% in the Cariboo Forest Region. Lodgepole pine is now the second ranking species, comprising about 24% of the annual provincial harvest. It has not, however, always been a commercially sought species, accounting for less than 5% of the harvest in the 1960s and only 2% in 1955. Not surprisingly, then, a large proportion of this species is mature and overmature; by area, more than half is more than 80 years old and almost three-quarters is more than 60 years old. It is these older trees that have been most susceptible to attack.

Mountain pine beetle outbreaks have been recorded within British Columbia at irregular intervals since at least 1910. Particularly notable early infestations occurred in the Princeton, Okanagan Valley, and Lillooet areas, and:

- from 1930 to 1936 vast areas were infested in central British Columbia;
- from 1930 to 1943 large infestations included Kootenay, Yoho, and Banff national parks;
- from 1946 to 1965 infestations were around Babine Lake in northcentral British Columbia and in scattered western white pine stands on Vancouver Island; and,
- from 1972 to 1977 all mature pine in the Kleena Kleene Valley in west-central British Columbia were killed.

CURRENT OUTBREAK STATUS

The current province-wide outbreaks started during the early 1970's, culminating in 1984 when red trees (recent faders) were present over more than 482 000 ha in British Columbia (fig. 2). By 1987 the area and volume of pine killed had declined to the lowest level in 7 years. However, more than 8900 infestations are still active on more than 66 400 ha widely distributed from the international border to north of Prince Rupert (fig. 1). This is almost double the area burned by forest fires in British Columbia in 1987. The volume killed, about 3.0 million m^3 in 1987, represents about 16% of the lodgepole pine volume harvested annually in the province and many forest companies are operating solely in mountain pine beetle salvage areas. Since 1972 more than 204 million mature trees have been killed by mountain pine beetle in British Columbia.

In Alberta and Saskatchewan, populations have generally returned to endemic levels (Cerezke in press) after infestations in the early 1980's spread over 7750 ha mostly in Waterton Lakes National Park as well as the adjacent Castle River area and spot infestations occurred throughout the Porcupine and Cypress Hills (Anonymous 1986).

The decline in infestations is due in part to major control programs, to depletion of susceptible host material in many areas, and, to a large degree, to overwintering brood mortality mainly in central British Columbia and Alberta caused by early, below-normal temperatures in late 1984 and again in 1985. In the Cariboo Region, which in 1985 accounted for at least 65% of the province's infested area, minimum temperatures below -30°C in October and -45°C in December 1984 virtually eliminated beetle populations. Slower development influenced by the cool wet summers of 1983 and 1984 probably also made the populations more susceptible to the early cold snap.

Populations elsewhere were less affected. In 1987, mountain pine beetle remained active over 19 000 ha in the Kamloops Region and 23 100 ha in the Nelson Region, especially in the western districts, and declined to 1470 ha in the Vancouver Region. In the Prince Rupert Region there was a 25% increase

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G.A. Van Sickle is Head of the Canadian Forestry Service's Forest Insect and Disease Survey at the Pacific Forestry Centre, Victoria, British Columbia.

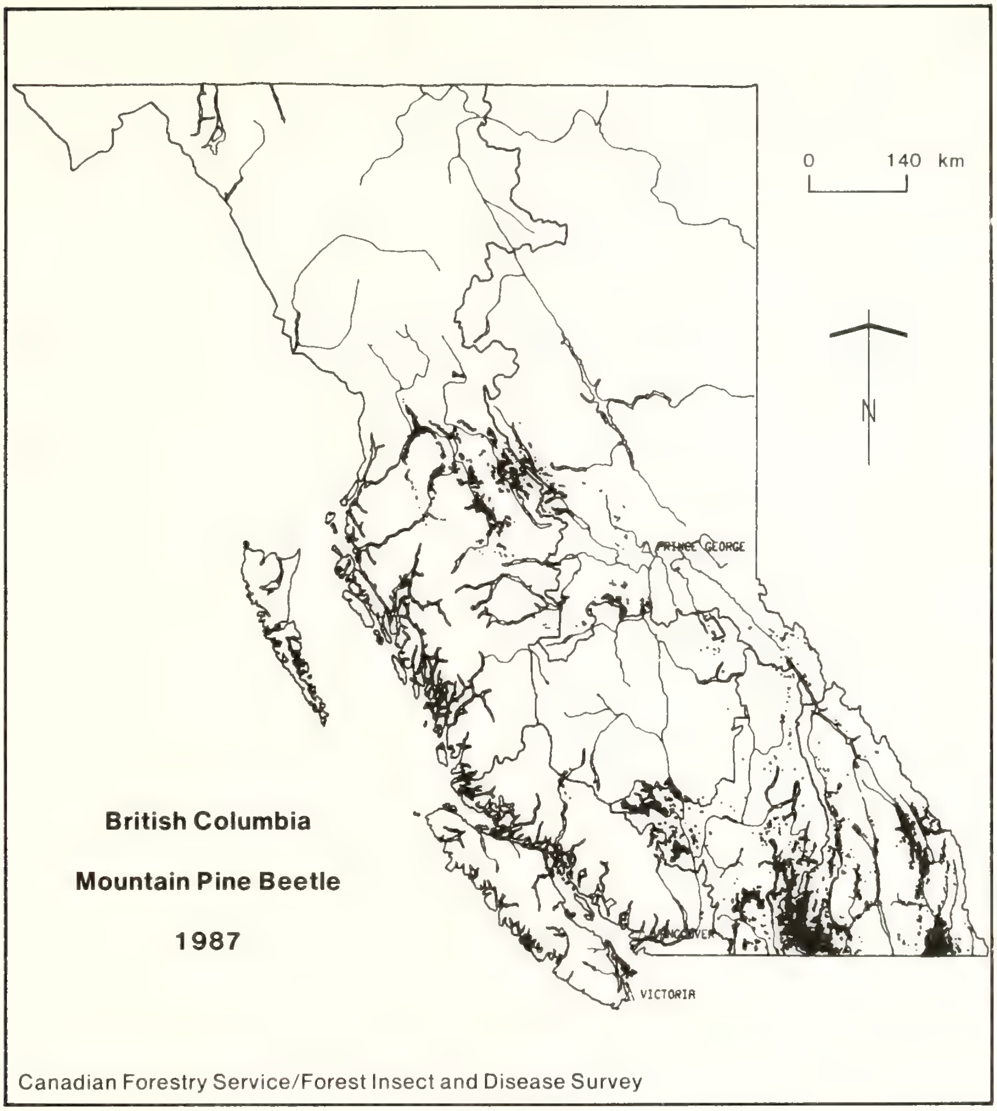

Figure 1--Areas where recent tree mortality due to mountain pine beetle was detected during aerial surveys in 1987.

to 18 600 ha and in the Prince George Region a threefold increase to 4300 ha, mostly northwest of Fort St. James. In the westernmost portion of the Cariboo Region, a new infestation developed over 500 ha, the first since the major winter kill.

Intensification and perhaps some spread is expected to become apparent in 1988. Based on stands cruised in the fall of 1987, the percentage of trees currently attacked averaged 20% (range 0 to 64%). This was an increase over 1986 levels and above the 12% average for red faders. New attacks were highest in the Prince Rupert and Prince George regions at 33% and 34%, respectively. Along the international border, new attacks averaged 13% in the Nelson Region and 6% in the Kamloops Region.

In southwestern Alberta, populations have declined to such a point that few recently killed lodgepole or limber pine were observed during aerial surveys. Placement of lures on 150 trees in the Kananaskis and Crowsnest Pass resulted in 47 attacked trees being cut and burned while a few remaining attacks were treated by removal of individual galleries. In the Cypress Hills, after 500 lures were deployed, only 20 fresh but unsuccessful attacks were recorded on the Alberta side and only five new attacks in three trees were recorded on the Saskatchewan side (Cerezke in press).

At the time of writing, overwintering brood survival and status in British Columbia is just being assessed. Overall, brood survival was good with more than 80% of the broods being healthy and vigorous. "Reproductive trend values", (i.e., the ratio of overwintering progeny to parent beetles) are ranging from 0 to 11.2: values greater than 4.0 indicate increasing populations. In the Nelson Region, the ratio averaged 4.1, indicating a continuing but reduced population expected to attack trees in 1988 which will fade in 1989. Five areas had increasing populations and four areas

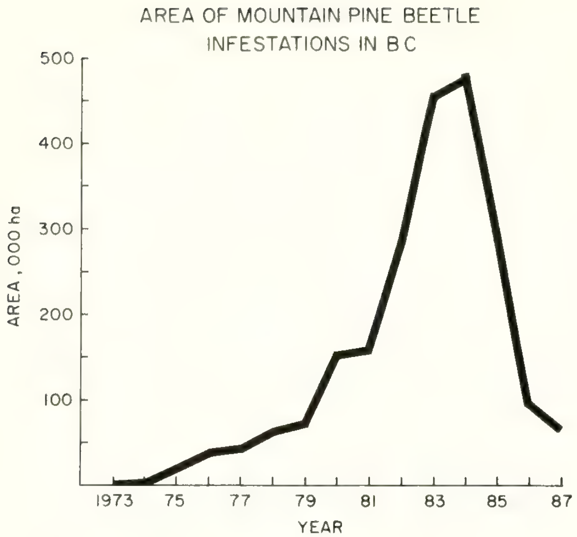

Figure 2--Area of new faders in mountain pine beetle infestations detected during annual aerial surveys from 1973 to 1987 in British Columbia.

were classified as static. In the Okanagan Valley of the Kamloops Region, seven of eight areas were increasing with an average value of 6.5. Stands to the west of the valley were mostly in a static class according to the bark beetle research group. In the Vancouver Region, values of 2.1 and 2.0 indicate a further slowing in an already declining population. Access difficulties in northern British Columbia reduced sampling, but in the western portion of the Prince Rupert Region values averaged 3.7 with four of nine stands classed as increasing, two static and three declining.

CONTROL PROGRAMS

To lessen the impact of mountain pine beetle on the sustainable annual harvest and to prevent its spread into vast uninfested areas, major bark beetle management programs were implemented in Alberta in 1980 and in British Columbia in 1984. In Alberta from 1980 to 1985, $6.2 million has been expended to encourage salvage and to detect and treat more than 107 000 infested lodgepole and limber pine trees (Anonymous 1986). In British Columbia, $37 million has been allocated in a planned 5-year, $50-million program started in 1984. This year about $8.1 million has been allocated to continue management activities including aerial photographic surveys, detection and delineation surveys, directed sanitation harvesting, single tree treatment projects, access construction, and use of aggregating pheromones (Hall personal communication).

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MOUNTAIN PINE BEETLE: BIOLOGY OVERVIEW

Les Safranyik

ABSTRACT: The general biology and ecology of the mountain pine beetle in lodgepole pine forests was reviewed with emphasis on insect-host interaction and causes of outbreaks. During endemic periods the beetles normally infest trees of low vigor such as injured, diseased or otherwise weakened trees and windfalls, usually in association with secondary bark beetles. Attack success in such trees tends to be high even at low attack densities but brood production is usually low. When the beetle populations switch from endemic to epidemic, the beetles infest proportionately more of the larger diameter trees in the stand. Many of these trees have thick phloem. Normally, such stands are more than 60 years old and the average diameter for trees 10 cm and larger is about 20 cm. Precisely which factors are responsible for triggering outbreaks is uncertain; however, all factors that would significantly reduce host resistance or increase the size of the beetle population above a threshold necessary for colonizing at least some of the large diameter trees with thick phloem could trigger outbreaks.

INTRODUCTION

The mountain pine beetle, Dendroctonus ponderosae Hopk., (Coleoptera: Scolytidae), a native insect in the pine forests of western North America, has been referred to as the most destructive bark beetle (Wood 1963). In areas where the beetle is common, it is the most important pest of mature lodgepole pine, Pinus contorta var. latifolia Engelm. During endemic periods, populations are innocuous, and only a few scattered infested trees are to be found. However, during outbreaks, which occur at irregular intervals and may persist for periods of 5 to 20 years, more than 80% of the host trees with a DBH of 10 cm or more may be killed over large areas.

In recent years, the losses caused by the mountain pine beetle, particularly in lodgepole pine, have been devastating. In British Columbia, for example, losses resulting from the 1983 attacks alone were estimated at 41 million trees killed in infested areas totaling 482 000 ha (Wood and others 1985). In infested stands managed for commercial production, the value of losses during epidemics is usually considerably greater than that indicated by the volume loss because most mortality is among the larger diameter trees. Outbreaks usually affect management plans and may create marketing problems. Outbreaks change stand density, age and species composition of stands, the size distribution of pine, and aesthetic values. Outbreaks also increase fuel loading, and hasten succession to the climax forest type.

The objectives of this overview are to provide a brief account of the population biology of the beetle in lodgepole pine forests, to highlight key features, and to identify gaps in the knowledge as a background to the main theme of the symposium. For more detailed descriptions of the population biology of the mountain pine beetle the reader is referred to Amman and Cole (1983) and other publications cited in this paper.

BIONOMICS

Geographic Distribution and Host Trees

The mountain pine beetle occurs in forests from northern Mexico (latitude 31°N) to northwestern British Columbia (latitude 56°N) and from the Pacific Ocean east to the Black Hills of South Dakota. It occurs up to about 750 m near the northern limits and up to about 3650 m near the southern limits of the beetles' range (Safranyik 1978).

The main hosts are lodgepole pine, ponderosa pine (P. ponderosa Laws.), western white pine (P. monticola D. Don), and sugar pine (P. lambertiana Douglas) (Amman 1978). This list of principal hosts is based on the commercial impact and intensity of epidemics. Other species of pine, including several exotic species within the range of the beetle, are infested and killed. Some non-host trees (e.g., Picea) are occasionally attacked and killed, but populations are usually not maintained in such trees.

Life Cycle

In the optimal portion of its range, the mountain pine beetle normally completes one generation per year. Brood adults typically mature in July. Young beetles are dark brown to black, and range in length from 3.5 to 7.5 mm. In order to complete maturation, they feed on the inner bark and on spores of blue stain fungi and yeasts which line the walls of the pupal chambers. During

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Les Safranyik is a Research Scientist, Pacific Forestry Centre, Canadian Forestry Service, 506 West Burnside Road, Victoria, British Columbia, Canada, V8Z 1M5

maturation feeding the flight muscles increase in size (Reid 1958) and the mycangium (a special structure on the head) becomes charged with fungal spores, which ensures transport of the fungi to new trees (Safranyik and others 1975).

Ambient temperatures are instrumental in determining the onset of emergence, the length of the emergence period, diurnal rates of emergence, and flight activity. Emergence normally begins after several days of warm, dry weather, but there is no apparent relationship between the duration of such warm periods and the onset of emergence (Safranyik 1978). Emergence and flight start at about 16°C, and rates of emergence are reduced at temperatures greater than 30°C. Peak daily emergence normally occurs during a period of 2-3 hrs in mid-afternoon when the temperature exceeds 20°C. The median dates of annual emergence can vary by as much as 1 month, but normally vary by 10 days or less. The period of peak emergence normally lasts a week to 10 days, but can vary from a few days to 3 weeks.

Beetles that do not disperse from the stand in which they develop usually locate suitable host trees within 2 days of emergence, but are capable of searching for several days. In release-recapture experiments using marked beetles in central British Columbia, one beetle was trapped at a baited tree 11 days after release more than 1 km from the release site. In the absence of pheromones, beetles tend to disperse downwind, mainly below the canopy in the clear bole zone, and search upwind only after an attractive pheromone plume is encountered. Very little is known about beetle flight above the canopy (other than that it occurs), or about long-range dispersal. Collection of mountain pine beetles in high-elevation snowfields in eastern British Columbia, Alberta, Washington (Furniss and Furniss 1972), and circumstantial evidence from elsewhere in the United States (Evenden and others 1943), indicates that long-range dispersals occur during outbreaks and may be significant factors in the spread of epidemics.

Searching adult beetles usually select and attack living trees during late July or early August. Fresh felled trees or windfall may also be attacked. Searching beetles land at random on host and non-host trees, hence one of the dominant theories of host selection states that initial attack by the pioneer beetles occurs at random, as opposed to being directed by some stress-induced "primary attraction." There is evidence, however, that dispersing adults land preferentially on lodgepole pines suffering from injury or disease (Gara and others 1984). As the pioneer female beetles bore into the bark, they release semiochemicals which attract both sexes and result in the aggregation of beetles on the focus tree, and eventually to close-range redirection of responding beetles to nearby trees (Borden and others 1986). In lodgepole pine, the beetles are strongly oriented to large-diameter trees. Vision is believed to play a key role in locating the host (Shepherd 1966). In addition to semiochemicals, physical and physiological host factors and beetle population size are thought to be important determinants of the density and distribution of attacks on the bole. On individual trees, mass attacks are normally completed within 1-2 days.

During gallery establishment, the beetles carry spores of the blue stain fungi, yeasts, and bacteria. These spores slough off along the walls of the galleries and grow in the living tissues. Although the roles of these organisms are not completely known, the blue stain fungi quickly invade and kill live cells, thereby preventing them from producing resin, which is the main defense of the tree against invasion by the beetle-microorganism complex. Blue stain fungi also effect a rapid reduction of moisture in the sapwood.

The female beetle bores through the bark and constructs an egg gallery averaging 25-30 cm in length in the phloem parallel to the grain. Mating takes place in the lower end of the egg gallery. The male often leaves after mating. The female plugs the gallery entrance and packs the lower end with boring dust. Usually 60-80 eggs, about 2 per cm, are laid singly in niches cut into the sides of the gallery. The eggs usually hatch in 1-2 weeks and the larvae feed in the phloem, roughly at right angles to the gallery. The larvae normally become dormant in late October or November and begin feeding again in April. Pupation takes place during mid to late spring and development is completed during late June to mid July.

There are exceptions to the 1-year cycle described above, and they depend primarily upon climate and weather (Safranyik 1985). The most common exceptions occur when many parent beetles establish two broods in a single warm, dry year, or in very cool years or at high elevations and latitudes where a proportion of the brood may require more than 1 year to complete development.

Brood Survival

Systematic studies of the nature and effect of factors affecting brood survival within and among trees have only been done on high endemic, epidemic, and postepidemic populations of the mountain pine beetle. Consequently, we have a poor understanding of brood survival and mortality factors in endemic populations.

It is generally believed that the same factors of mortality operate in both endemic and epidemic populations; however, the relative impact of some of these factors on brood survival, alone or in interaction with other factors, is considerably different at the two population states. For example, during endemic periods, often due to the low rates of attack, low attack densities, and perhaps also because of higher tree resistance, much higher proportions of unsuccessful attacks and higher brood mortality can occur than during epidemic periods.

Several life table studies from the United States (Amman and Cole 1981) suggest that during epidemics none of the natural, within-tree mortality factors investigated (competition,

predators and parasites, pathogens, drying of the bark, and resinosis) regulate beetle populations; survival of beetles at these times is more closely related to tree diameter and phloem thickness than any other factor. Reid (1963), based on population studies of a small infestation in southeastern British Columbia, found that tree diameter was the most important factor determining beetle survival.

The life table studies corroborated previous work (Cole 1974, 1975) showing that in areas where mountain pine beetle has mainly a 1-year life cycle, winter temperatures and drying of the phloem are the two most important causes of within-tree mortality and their effects are inversely related to tree diameter. With the exception of the predaceous fly, *Medetera*, beetle mortality resulting from predators, parasites, disease and resinosis was considerably less than that recorded for temperature and bark drying; *Medetera* showed a density dependent response over time. Reid (1963) too showed the importance of low temperature and subcortical moisture for affecting brood survival within trees, but he also found competition (in terms of egg gallery density) and resinosis to be important factors.

In general, mortality factors that are most important during the 1-year life cycle cause similar levels of mortality when more than 1 year is required to complete a generation (Schmitz 1985). However, at higher elevations and northern latitudes, cool temperatures that delay development and increase winter mortality replace food (phloem thickness) as the main factor limiting population survival.

In the life table studies referred to above, about one-half of total mortality was caused by unknown factors. This is a rather typical result for bark beetle population studies in general and emphasizes the need for better knowledge of mortality factors and improved experimental procedures.

Mortality within trees is just one component of total mortality in each bark beetle generation. We have inadequate knowledge of mortality among emerged beetles during the dispersal-host finding phase. This mortality may be 60% or higher, depending on population levels in relation to host availability, weather, and other factors, and may be one of the key factors limiting population growth at endemic and postepidemic levels.

Epidemiology

Under endemic conditions the mountain pine beetle often infests trees of poor vigor which were first infested by secondary bark beetles such as *Ips* and *Pityophthorus* spp. (Amman 1978), or attack injured, diseased, defoliated or otherwise stressed trees, and windfalls. High endemic or incipient infestations, which characteristically kill small groups of trees, are often found in draws, gullies, along edges of stand openings, or in areas subjected to soil compaction or wide fluctuations in the water table (Safranyik and others 1974). These incipient infestations may develop into outbreaks in a few years or may continue, especially in lodgepole pine stands of poor site quality, until most of the large-diameter pine component are killed. A major exception to this pattern of outbreak development occurs when local populations are augmented by the influx of large numbers of beetles from nearby infested stands, especially those at lower elevations. In this case, low populations and damage levels in a given year in some areas could be followed by epidemic infestations in the following years.

Outbreaks in lodgepole pine last from 3 to 20 years, range in size from a few hectares to hundreds of square kilometers, and invariably deplete the large-diameter component of stands (Safranyik and others 1974). In areas with cooler climates, such as areas at high elevations and northern latitudes, the intensification and spread of outbreaks tend to be less but outbreaks may persist longer than in areas within the beetle's optimum range.

During mountain pine beetle epidemics, large populations of secondary bark beetles usually build up in the tops and other sections of the bole and large branches of trees killed by mountain pine beetle. Following the decline of mountain pine beetle epidemics, these secondary bark beetles, especially *Ips* and *Pityogenes*, attack and kill some of the remaining pines, mostly in the smaller diameter classes. Occasionally, tree killing can be extensive, but it rarely lasts longer than 1-2 years.

CAUSES OF OUTBREAKS

Although a great deal is known about the population ecology of the mountain pine beetle in lodgepole pine, our knowledge of how the transition from endemic to epidemic populations occurs is uncertain.

In natural lodgepole pine stands, outbreaks usually occur when the average age of the pine component is about 80 years or more and the average diameter of the pine greater than 10 cm is about 20 cm. Outbreaks usually develop in areas that are climatically most suited for beetle development and survival. Proportionately more of the large diameter trees are killed (Hopping and Beall 1948; Cole and Amman 1969). Brood production from infested trees is directly proportional to the thickness of the inner bark (Amman 1972; Berryman 1976).

Resin production in response to invasion of the beetle-blue stain fungi complex is a measure of host resistance to attack (Reid and others 1967), and is normally greatest in the largest diameter, fastest growing trees at a given age and site quality (Shrimpton 1973). At the stand level, resistance tends to be the greatest near the culmination of current annual increment (between 40 to 60 years, depending on site quality) and declines rapidly with increasing age (Safranyik and others 1975). The culmination of stand resistance corresponds to the attainment of the greatest basal area, biomass, and nitrogen

accumulation in lodgepole pine ecosystems following a stand-replacing fire (Fahey and Knight 1986).

As average phloem thickness is related to basal area growth during the preceding 6- to 10-year period (Shrimpton and Thomson 1985), both phloem thickness and resinosis are directly related to tree or stand vigor. Consequently, there is an apparent paradox in our information: if epidemic infestations can only be maintained in large diameter trees with thick phloem and if these are also the trees that tend to be the most resistant, how then can the switch from endemic to epidemic occur at all? We do not have definite answers, but a plausible explanation is as follows: It is generally acknowledged that the degree of host response to attack and host suitability for mountain pine beetle reproduction is dependent on beetle numbers, at least at low population levels (Raffa and Berryman 1983). Consequently, as the beetle population increases, trees of higher resistance become available for colonization and outbreaks are triggered when a threshold of beetle numbers is attained that can successfully colonize large diameter trees with thick phloem (Berryman 1978). This beetle population threshold may be exceeded in stands suffering from temporary weakening such as that caused by drought or defoliation, or from decline of tree vigor following attainment of physiological maturity (reduction of phloem thickness follows growth reduction with considerable time lag). The threshold may also be exceeded when endemic subpopulations within scattered weakened trees are close enough to concentrate attacks on one tree or a small group of trees of medium to large diameter and moderate to thick phloem (Amman 1978), or when large numbers of beetles disperse into a stand from other infestations. If weather conditions are unfavorable for the beetle, these incipient infestations will decline and several years may elapse before conditions for the development of an epidemic occur again.

Better understanding of outbreak development is of great practical importance for development of better systems for predicting outbreak hazard, and for development of more effective methods of management to reduce losses. More knowledge is urgently needed on population dynamics in the endemic state, qualitative differences between endemic and epidemic beetle populations, primary attraction and chemical communication, the role of host tree injury and stress factors in triggering outbreaks, and the role of dispersal in the spread of epidemics.

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LODGEPOLE PINE: AN ECOLOGICAL OPPORTUNIST

Wyman C. Schmidt

ABSTRACT: Lodgepole pine is a persistent opportunist found in a remarkable variety of ecological zones in the U.S. and Canadian mountain West. Classification systems for biogeoclimatic zones and ecological habitat types populated by lodgepole pine are described. Information that relates habitat types where lodgepole is found with mountain pine beetle susceptibility is included.

INTRODUCTION

This is a story about an ecological opportunist of the Mountain West--lodgepole pine (Pinus contorta var. latifolia Dougl.). The story actually began eons ago, but it repeats itself time and time again in an ecological clocklike cycle. If you could collapse 100-200 years into a 24-hour time period it would go like:

Time	Event
2400 Midnight	Fire
0000 - 0200	Lodgepole pine regeneration
0200 - 1600	Stand development
1600 - 2000	Bark beetle (Dendroctonus ponderosae Hopk.) epidemic
2000 - 2400	Fuel buildup
2400	Fire
0000 - 0200	Lodgepole pine regeneration
0200 - 1600	Stand development
1600 - 2000	Bark beetle epidemic
2000 - 2400	Fuel buildup
2400	Fire
0000 - 0200	Lodgepole pine regeneration
0200 - 1600	Stand development
1600 - 2000	Bark beetle epidemic
2000 - 2400	Fuel buildup
2400	Fire
	(and on and on infinitely)

Now, if you throw in an occasional ice age in western United States and Canada to give it a little variety, you have the "Rest of the Story" of long-term succession of ecosystems through time in lodgepole pine forests.

Lodgepole pine goes through this ecological cycle on a large proportion of its domain unaccompanied by its conifer and broadleaf associate species. However, in many areas lodgepole pine has a large variety of companion species that have similar silvical requirements and fall into the same clocklike succession. These companions usually slow or accelerate the successional process.

So the story gets somewhat more complicated then first indicated. But to really complicate it put man into the equation. He does not like fire; he does not like beetles; he would like to utilize the woody fuels that just burn up in wildfires; he would like to regenerate trees faster than nature does alone; he would like to grow bigger trees faster. He wants lodgepole pine forests to look esthetically pleasing throughout this whole process (even though nature itself can't always accomplish this); he wants the forests to be desirable for wildlife and water production, and on and on.

Most managers want to be able to predict and regulate what will happen in a somewhat more limited time and space than described earlier. Since some of these effects will be covered in other papers of this symposium, this paper will focus on the ecological aspects of lodgepole pine forests that currently occupy the vast slopes and valleys of the Mountain West.

GENERAL ECOLOGICAL PERSPECTIVES

Why call lodgepole pine an opportunist? Lodgepole pine grows in an extremely wide range of ecological conditions: from low to high elevations, from relatively dry to wet conditions, from warm to cold, on most every soil condition found in the West, has two modes of seed dispersal, has rapid juvenile growth to start it out in a dominant position in the stand, and has other attributes it needs to truly make it an aggressive opportunist (Schmidt 1982).

But lodgepole pine pays the price for some of its opportunistic ways. It is short-lived compared to most of its associate species. It is highly susceptible to bark beetles at a relatively early age; the largest lodgepole pines in the stand are the favored targets for the bark beetle. It is subject to diseases that can debilitate it. But, overall, this versatile species holds great potential for intensive management over vast areas of the West (Schmidt and Alexander 1984).

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Wyman C. Schmidt is Project Leader and Research Silviculturist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Bozeman, MT 59717.

The ecology of lodgepole pine forests is made up of a whole spectrum of variables such as fire frequency, elevation, topographic position, associated vegetation, edaphic factors, stand density and homogeneity, site quality, geographic location, insects, and disease. Mix all of these and a few other as yet unidentified factors and you have the beginnings of an equation that helps describe lodgepole pine forest ecology. Combine this information with classifications such as forest cover type, ecological habitat type, biogeoclimatic zone, or some other classification and you begin to provide a recipe that helps describe and communicate what is up at the head of Elk Creek, or management zone B, or stand number 28, or T25NR16W, Sec. 6, or other locations with similar designations.

Ecologists have had a long history of disagreements on terminology and how to describe and classify vegetation and site. Some classifications are based on the vegetation presently occupying the site such as cover types (Eyre 1980); others are based on the potential or climax vegetation that can be expected in the long term on the site (Daubenmire 1966).

However, most ecologists do agree on the concept of succession, the progressive development of ecosystems through time, and how climax and seral vegetation fit into that mold. That agreement simplifies the discussion of lodgepole pine. With minor exceptions, lodgepole pine is a seral species with remarkable ecological amplitude. Lodgepole pine is highly intolerant of shade and although some seedlings may become established under a forest canopy they seldom grow to maturity unless released. As a result, most lodgepole pine forests are essentially even-aged and relatively homogeneous. Barring any major disruptive event, such as fire, lodgepole pine is usually succeeded by more shade-tolerant species such as Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.). This succession proceeds at different rates, moving relatively fast on the lower elevation mesic sites and particularly slow in high-elevation forests such as those extensive stands along the Continental Divide area of Montana (Lotan and Perry 1983).

Pfister and Daubenmire (1975) described what they felt were four basic successional roles for lodgepole pine.

1. Minor seral - lodgepole pine is a minor component in young, even-aged, mixed species stands which are replaced by more shade-tolerant associates in 50 to 200 years. The most rapid transition occurs on the more mesic sites.

2. Dominant seral - lodgepole pine is the dominant cover type of even-aged stands. Vigorous understory shade-tolerant trees will replace the lodgepole in 100 to 200 years.

3. Persistent - lodgepole pine forms the dominant cover type of even-aged stands with little evidence of replacement by shade-tolerant species. This usually occurs because other species are not present due to inadequate seed sources or the sites are poorly suited to other species.

4. Climax - lodgepole pine is the only species capable of growing on some sites and it perpetuates itself. This is most commonly found on sites where soils hold only limited moisture and sometimes where frost pockets occur. These types of site conditions usually result in uneven-aged stands that are climax in character (Franklin and Dyrness 1973). They are often droughty edaphic situations such as the obsidian sands in the Yellowstone Park area and similar conditions in central Oregon.

ECOLOGICAL CLASSIFICATIONS

One of the first approaches to understanding any kind of organism or groups of organisms is to separate them into some type of class whether by composition, reproductive habit, growth habit, color, size, age, or other criteria. Separation into classes permits orderly description that can then be made to provide a common mode of communication.

Although very complex in most cases, classification systems that include lodgepole pine as major and minor components have been developed for ecosystems in both the United States and Canada. As more and more information is being developed for the various ecological classifications a greater amount of predictability should be forthcoming.

Terminology differences can be a stumbling block in utilizing classification methods. The plant association, as defined by Daubenmire and Daubenmire (1968), is the aggregation of all climax forests that have essentially the same dominant species and biotic potential. Habitat types, as developed for the northern and central Rockies of the United States, and plant associations in the Pacific Northwest, illustrate this classification concept. Those habitat types and associations that have the same potential dominant climax species form what are called series. The term community type is used to name a type of recurring vegetation where climax has not been verified (Daubenmire 1976).

Table 1--Ecological amplitude of lodgepole pine in various geographic areas (from Lotan and Perry 1983 and adapted from Pfister and Daubenmire 1975)

Geographic area	Occurrence of lodgepole pine
Northern Idaho and eastern Washington	12 of 22 forest habitat types
Boise and Payette National Forests, ID	25 of 33 forest habitat types
Sawtooth Range to Pioneer Mountains, ID	9 of 14 forest community types
Wind River Mountains, WY	4 of 5 forest habitat types
Medicine Bow Mountains, WY	2 of 5 forest habitat types
Western Montana	18 of 30 forest habitat types
Central and eastern Montana	30 of 45 forest habitat types
Subalpine forests, Utah	2 of 4 forest habitat types
East slope of the Front Range, Colorado	6 of 16 sample stands
Colorado Front Range, CO	3 of 3 forest zones
Ochoco National Forest, OR	3 of 7 forest associations
Pumice region of central Oregon	6 of 6 forest communities
Subalpine forests, southern Washington	4 of 15 forest habitat types
British Columbia	9 of 11 biogeoclimatic zones
Similkameen Valley, BC	3 of 7 forest habitat types
Douglas-fir zone of interior British Columbia	4 of 4 forest community types
South-central interior, British Columbia	10 of 14 site types
Rocky Mountains, AB	16 of 23 forest habitat types

Excellent summaries have recently been prepared for various aspects of lodgepole pine ecology and management (Lotan and Perry 1983; McGregor and Cole 1985; Pojar 1985; Volland 1985). To get a better perspective on the ecological amplitude of lodgepole pine, Lotan and Perry (1983) summarized information that had been developed about the occurrence of lodgepole pine in the various geographic areas throughout its range (table 1). Eight different types of vegetation classifications comprised the summary. As noted in their summary, lodgepole pine occurs in over 60 percent of the vegetation classes developed for the geographic areas they describe.

Volland (1985) noted in his summary on the ecological classification of lodgepole pine in the United States that lodgepole pine has been described as a seral species in 114 associations and 15 different tree series. He felt that lodgepole pine was a persistent seral member in another 21 plant communities and a climax species in 33 associations. He graciously provided a detailed listing of all these series and communities as well as the reference information.

Pojar (1985) summarized the ecological classifications used for lodgepole pine in Canada. Although other systems are used in some areas, by far the most commonly used ecological classification in the range of lodgepole pine in Canada is the biogeoclimatic ecosystem classification. This classification results from a synthesis of climate, vegetation, and soil data. It was developed primarily by Krajina and his students (1965, 1969) and has been used for much of British Columbia and Alberta. It is being developed as a multi-level hierarchy with emphases on ecosystem and zonal levels.

Ecosystem classes are based mostly on small areas relatively homogeneous in vegetation and soils while biogeoclimatic classes are based mostly on regional climate, vegetation, and soils. In simple terms, the biogeoclimatic zones are quite broad and the ecosystem categories are relatively narrow.

Alberta and British Columbia forests are divided into nearly 20 of these biogeoclimatic zones, and lodgepole pine occurs in all but three of the zones. Pojar (1985) illustrated the ecological amplitude of lodgepole pine with a table of occurrence in several different biogeoclimatic zones as follows:

Biogeoclimatic zone	Occurrence of lodgepole pine
Montane spruce	24 of 29
Sub-boreal spruce	64 of 106
Engelmann spruce-subalpine fir	44 of 80
Boreal white and black spruce	12 of 29
Interior cedar-hemlock	37 of 92
Interior Douglas-fir	29 of 83

Table 2--Relationship of bark beetle infestations to habitat type and elevation in S.E. Idaho and N.W. Wyoming (adapted from Roe and Amman 1970)

Habitat type	Elevational range of stands	Stands infested with bark beetles
	(feet)	(percent)
Abies lasiocarpa/ Vaccinium scoparium (cold and moist)	6,500-8,500	44
Abies lasiocarpa/ Pachistima myrsinites (warm and moist)	6,700-7,800	92
Pseudotsuga menziesii/ Calamagrostis rubescens (warm and dry)	6,000-7,800	64

ECOLOGICAL CLASSES AND THE BEETLE

It would be great to be able to say that we know which eco-classes containing lodgepole pine are most, least, or moderately susceptible to mountain pine beetle attack, how much these attacks would impact lodgepole pine stands, when this would occur, and what we can do to help alleviate the problem. Unfortunately we are not there yet, and the information to date has been difficult to interpret, but we do have some hints about the relationship of bark beetle activities in different ecological classes.

One of the first significant attempts at relating beetle activity to ecological habitat types was made by Roe and Amman (1970). They concluded that active infestations in southeast Idaho and northwestern Wyoming varied by habitat type with the heaviest infestations in the most mesic habitat type--Abies lasiocarpa/Pachistima myrsinites--as shown in table 2. However, this was complicated to some extent by elevational overlaps between habitat types. Elevation has always been regarded as a significant factor in bark beetle infestations, with the very high elevations less hospitable to the bark beetle. The Roe and Amman study area was limited geographically and, as shown in table 2, habitat types in the study area overlapped in their elevational distribution. Both the limited geographical area and elevational overlap tend to add credence to the ecological habitat relationship to beetle activity.

McGregor (1978) evaluated beetle mortality of lodgepole pine in relation to elevation and ecological habitat types on what he classified as dry mountain slopes and moist mountain slopes in Montana. He concluded there were mortality differences, in terms of basal area of trees ≧ 8 inches DBH, between habitat types on the dry slopes. But, mortality varied only from 40 to 42 percent on the three lower elevation habitat types--Abies lasiocarpa/Vaccinium scoparium - Calamagrostis rubescens, the Abies lasiocarpa/Calamagrostis rubescens, and the Pseudotsuga menziesii/Calamagrostis rubescens-Calamagrostis rubescens. Meanwhile, the higher elevation (about 8,000 ft) Abies lasiocarpa/Vaccinium scoparium-Vaccinium scoparium habitat type showed 25 percent mortality. The moist slopes showed greater differences in beetle mortality within the same general elevation zone but again, the two lower elevation habitat types Picea/Linneae borealis and Abies lasiocarpa/Linneae borealis had about twice the mortality of the upper elevation habitat types with 40 percent mortality of trees ≧ 8 inches DBH. Mortality upslope was 20 percent on the Abies lasiocarpa/Vaccinium globulare and 13 percent on the Abies lasiocarpa/Alnus sinuata habitat types.

Unfortunately, most analyses of these types of data are not inclusive enough to permit separation of the effects of individual site and stand variables such as elevation, slope, aspect, host/non-host ratios, age, and stand density from that of ecological habitat type or classes as such.

An indirect method of relating potential mountain pine beetle damage to ecological habitat type is through the beetle's food source, the phloem of lodgepole pine. Cole's (1973) analyses of phloem thickness showed ecological habitat type groups as the second most important variable, after basal area increment, in predicting phloem thickness. His statistical evaluations indicated Pseudotsuga menziesii/Physocarpus malvaceus, Pseudotsuga menziesii/ Symphoricarpos albus, and Abies lasiocarpa/Pachistima myrsinites could be grouped to predict phloem thickness and that the combination of Abies lasiocarpa/Vaccinium scoparium and Pseudotsuga menziesii/Calamagrostis rubescens could also be grouped together for phloem predictions.

McGregor and Cole (1985) examined integrated strategies for dealing with mountain pine beetle problems where multiple resources were at stake in lodgepole pine forests. In those guidelines, Pfister and Cole (1985) described the successional role of lodgepole pine relative to different habitat types and assigned lodgepole pine to four successional roles: usually minor seral, often dominant seral, usually dominant seral, and persistent climax (table 3).

Cole (1985) further elaborated on the ecological relationships, using habitat types as a framework, and described the character and number of habitat types and their successional roles for the Gallatin and Flathead National Forests in Montana. When combined with stand characteristics of basal area and size classes, the combined information provides a good tool for examining potential management opportunities and problems such as bark beetles.

A current study by Cole (1983) should start to provide more definitive answers about the relationship of ecological habitat type to bark beetle activity in intermediate age stands. This study addresses the relationship of bark beetles to managed stands and how these interact with the variables of age, stand, and site factors within an ecological habitat type matrix.

DISCUSSION

There is a current adage that says "We've come a long way baby." We have. Much has been accomplished in learning the ecological facts about lodgepole pine forests throughout its range in the United States and Canada, and there are several recent publications that do a good job summarizing this information. In spite of the fact that not everyone agrees on ecological terminology, most everyone agrees that ecological classifications are an extremely useful working tool in describing and communicating about forest types.

Perhaps our biggest challenge in effectively utilizing classifications both north and south of the U.S./Canada border lies in being able to tie other factors to the zones or classes such as tree growth, water production potentials, wildlife habitat, esthetic values, potential disease and insect problems, and the like. Some of these factors will cross many of the strata in the classifications, others may be restricted to one strata or part of a strata. It is when we can determine how a particular factor behaves within or between strata of the vegetative classifications that we will fully realize the value of the ecological classifications.

Unfortunately, we have a fair distance to go before we have the relationship of bark beetles and ecological habitat type or other forest and land classifications deciphered. There are, however, some things that we can say with some degree of confidence, such as:

1. Mountain pine beetle infestations can easily cross the boundaries of most of the ecological strata of currently used classifications--they are not a respector of ecological boundaries formed by classifying vegetation or other components.

2. Groupings of vegetative or biogeoclimatic zones or perhaps series may prove more realistic for delineating and predicting beetle activities. Beetle zones appear to be much broader than the present vegetative classes. There are enough hints already to proceed with efforts to quantify some of these relationships.

3. Bark beetles appear to be most damaging in the mid-range of water and temperature gradients of lodgepole pine forests.

4. A better understanding of the successional patterns on the large number of ecological zones or habitats in which lodgepole pine occurs would help considerably in understanding the beetle/stand/site relationships.

5. Greater uniformity in ecologists' terminology would enhance the opportunity for communication in relating beetle activity to ecological zones or features.

6. Lodgepole pine and mountain pine beetles have co-existed successfully for eons and both qualify as being opportunists. They are so closely linked ecologically that minor disruptions in the natural succession can likely be expected to significantly affect the other species positively or negatively. Learning to capitalize on this feature is a promising management tool.

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Table 3--Habitat types where lodgepole pine is a component, by successional roles (adapted from McGregor and Cole 1985)

USUALLY MINOR SERAL

Montana	Northern Idaho	Northwestern Montana
Warm-dry	Cool-moist	Cold-moist
Douglas-fir/ snowberry	Grand fir/ queencup beadlily	Subalpine fir/ smooth wood-rush
Douglas-fir/ ninebark	Grand fir/ twinflower	Mountain hemlock/ menziesia
Subalpine fir/ virgin's bower	Western hemlock/ queencup beadlily	Mountain hemlock/ smooth wood-rush
	Western redcedar/ queencup beadlily	

OFTEN DOMINANT SERAL

Montana			Northern Idaho & Northwestern Montana
Warm-dry	Cool-moist	Cold-dry	Warm-moist
Douglas-fir/ twinflower	Spruce/ ninebark	Subalpine fir/ elk sedge	Subalpine fir/ queencup beadlily
Douglas-fir/ pinegrass		Subalpine fir/ whitebark pine/ grouse whortleberry	

USUALLY DOMINANT SERAL

Montana			Northern Idaho and Northwestern Montana	
Dry	Moist	Cold-moist	Cold-dry	Cold-moist
Douglas-fir/ common juniper	Douglas-fir/ Dwarf huckleberry	Subalpine fir/ bluepoint	Grand fir/ beargrass	Subalpine fir/ menziesia
Subalpine fir/ pinegrass	Spruce/ queencup beadlily	Subalpine fir/ twinflower	Douglas-fir/ blue huckleberry	Mountain hemlock/ beargrass
	Spruce/ sweetscented bedstraw	Subalpine fir/ grouse whortleberry	Subalpine fir/ beargrass	
	Spruce/twinflower			
	Spruce/ starry Solomon's seal			
	Spruce/ dwarf huckleberry			
	Subalpine fir/ blue huckleberry			
	Subalpine fir/ Sitka alder			
	Subalpine fir/ heartleaf arnica			
	Subalpine fir/ sweetscented bedstraw			

PERSISTENT CLIMAX

Central and Eastern Montana	
Cold-dry	
Subalpine fir/dwarf huckleberry	Lodgepole pine/dwarf huckleberry
Lodgepole pine/twinflower	Lodgepole pine/pinegrass
Lodgepole pine/grouse whortleberry	Lodgepole pine/bitterbrush

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DETECTION AND SURVEY METHODS

FOR

MOUNTAIN PINE BEETLE

R. Ladd Livingston

Detection surveys for mountain pine beetle are generally conducted from the air. Usually this is done as part of an annual pest detection survey where newly infested spots are marked on a map for later reference. Due to the annual nature of these surveys, population trends can be followed. Computerized mapping and data summaries of the aerial sketch map information can greatly aid this detection and survey work.

As a new survey tool, semiochemicals are being used by the Canadian provinces of Alberta and Saskatchewan to monitor low level beetle populations and to attempt to detect increases of activity. Mountain pine beetle pheromones are being deployed as tree baits to provoke attacks on baited trees (Van Sickle 1988).

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R. Ladd Livingston is Forest Entomologist and Supervisor of the Insect and Disease Section, Idaho Department of Lands, Coeur d'Alene, ID.

Once the location of a new outbreak is known, evaluations can be conducted to determine the need for follow-up action and to determine the type of action that might be required. Standard forest cruising techniques have been incorporated with computer programs to produce volume tables of standing green and pest-infested trees. Also, for outbreaks of the mountain pine beetle in lodgepole pine, this program will make predictions of 10-year losses and of residual stand volumes after the outbreak has subsided (Bousfield and others 1985).

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PRELIMINARY EVALUATION OF HAZARD AND RISK RATING VARIABLES FOR MOUNTAIN PINE BEETLE INFESTATIONS IN LODGEPOLE PINE STANDS

Gene D. Amman and John A. Anhold

ABSTRACT: Difficulty in deciding on the most appropriate from among the many methods available for assessing lodgepole pine stand hazard and risk to mountain pine beetle infestation prompted an evaluation of these methods as part of the Canada/United States Mountain Pine Beetle Program. As a first step, some of the variables used in hazard and risk rating methods were analyzed by multiple regression to determine those with which the percent tree mortality was most closely correlated. These variables were found to differ by geographic area. Preliminary results suggest that best results in predicting hazard or risk will be achieved on an individual stand basis, and that tree size (positively related to tree mortality) and stand density (negatively related to tree mortality) will be important variables in any hazard or risk rating system.

INTRODUCTION

Hazard and risk rating methods to assess infestation potential of mountain pine beetle (MPB) (Dendroctonus ponderosae Hopkins) in lodgepole pine (Pinus contorta Douglas) stands are important tools to help deal with the MPB problem. These methods are designed to help land managers identify stands in which MPB epidemics are most likely to erupt and how much loss of timber is likely to occur.

There are many hazard and risk rating methods for assessing mountain pine beetle infestations in lodgepole pine stands. This profusion of methods is confusing--users are uncertain which should be used. Few have been adequately tested in the geographic area where they were developed, much less in other geographic areas. Therefore, as part of the Canada/United States Mountain Pine Beetle Program, a test of the various hazard and risk rating methods was undertaken over the range of mountain pine beetle distribution in lodgepole pine. We report some preliminary results for the western United States. Terry Shore (these proceedings) reported those for western Canada.

The objectives were to determine (1) which of the hazard and risk rating methods does the best job for a given geographic area, and (2) if a different set of parameters would do a better job of predicting hazard and risk than those now in use. The objective of this paper is to examine factors that were most closely associated with lodgepole pine mortality caused by MPB. The objective of determining how well the various hazard and risk rating methods performed cannot be fully assessed until sampled stands are revisited and total tree mortality determined.

RISK AND HAZARD

The terms "hazard" and "risk" are often used synonymously. However, we will follow the definitions given by Waters (1985):

> "Hazard is determined by tree, stand, site, and climatic factors that basically influence the probabilities of tree mortality. For individual trees, this means tree qualities or characteristics that affect the likelihood of successful beetle attack, for example, age or size, vigor, location. For a stand or area, it refers to factors affecting the likelihood of an outbreak occurring in that stand or area, for example, species composition, age-size structure, density, soil type, precipitation, disturbance--or more gross measures such as habitat type, elevation, or landform.
>
> "Risk, on the other hand, is a function of beetle abundance and distribution. Regardless of inherent hazard, a significant number of beetles must be in the general proximity for tree mortality to occur. Thus, a high hazard tree or stand may exist for years--to harvest, perhaps--without being infested. Conversely, a low hazard tree or stand may be considered at high risk--and successfully attacked--if within the area of an ongoing outbreak."

Hazard to MPB infestation has been related to a number of tree, stand, site, and climatic factors. These differ by geographic area and include the following: tree age and d.b.h.; latitude and elevation (Amman and others 1977); tree d.b.h.; culmination of current and mean annual increment and weather (Safranyik and others 1974); periodic

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Gene D. Amman is Principal Entomologist, Mountain Pine Beetle Population Dynamics Research Work Unit, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Ogden, UT. John A. Anhold is Entomologist, Forest Pest Management, Northeastern Area State and Private Forestry, Forest Service, U.S. Department of Agriculture, Durham, NH.

growth ratio (PGR)--current 5 years' radial growth divided by the previous 5 years' radial growth (Mahoney 1978); crown competition factor and percent lodgepole in a stand (SHR) (Schenk and others 1980); PGR divided by SHR and the percent basal area containing phloem 0.1 inch or thicker (Berryman 1978); quadratic mean diameter and number of growth rings in the last centimeter of radial growth (Stuart 1984); stand density index (SDI) (Anhold and Jenkins 1987); habitat type (Cole and McGregor 1983; McGregor 1978; Roe and Amman 1970); and growth efficiency (Waring and Pitman 1980; Waring and others 1980)--grams of stem wood produced per square meter of foliage, using sapwood area as a predictor of foliage area.

The resinous response of trees to inoculation of blue-staining fungi (Ceratocystis clavigera [Robinson-Jeffrey and Davidson] Upadhyay) (Raffa and Berryman 1982; Shrimpton 1973) also has been used as a measure of tree susceptibility to MPB infestation. Those trees having the greatest resinous response were considered least likely to be infested by MPB. However, in a field test of the method the tree response to fungal inoculation did not distinguish between susceptible and nonsusceptible trees to MPB infestation (Peterman 1977). The fungal inoculation method was not included in this test because it is quite time consuming.

Regardless of which hazard factors are used, beetle population size (risk) plays a very important role. An illustration of risk was given by Nebeker and Hodges (1983). In this illustration, trees with different abilities to withstand beetle infestation become susceptible to infestation, based on size of the beetle population. Until MPB infest trees suitable for good brood production--that is, trees of large diameter and thick phloem--an epidemic cannot start. Therefore, stands of lodgepole may contain all the elements for an epidemic of MPB, but because beetle numbers are low, an epidemic does not occur. When numbers are large, no tree is likely to be resistant to successful infestation.

Schmitz (in press) observed that during the endemic phase few MPB are present and are usually found in association with secondary bark beetles. These secondary bark beetles usually infest suppressed sapling or pole-size trees that are well below average in growth, have thin phloem, and are often partially girdled by porcupines. However, during an epidemic, the associates infest the tops of limbs of larger diameter trees killed by MPB the previous year. The secondary species usually overwinter in the adult stage in litter on the forest floor. They emerge during spring and infest trees soon after the snow melts. In contrast, the MPB emerge from late June to early September, depending on location. At endemic levels, only a few MPB emerge on any one day. Unless the time required to locate suitable trees to infest is minimized, a large proportion of such sparse populations is likely to succumb during dispersal. By utilizing trees already infested by other secondary scolytids, MPB dispersal losses are reduced. However, selection of trees that are already infested by secondary scolytids results in low MPB production because of small tree size, thin phloem, and infestation of only the basal 1 or 2 feet of the trunk. This behavior assures the MPB population will remain at a low level until the stand matures and beetles infest larger trees having thick phloem that will support high survival rates necessary for an outbreak.

METHODS

Several hundred stands of lodgepole were measured in the western United States. These were limited to the lower elevational levels where stands would be climatically susceptible to MPB infestation, thus making methods more directly comparable, since some have a climatic variable (Amman and others 1977; Safranyik and others 1974), where others do not. Outbreaks are not as likely to occur in the moderate to low areas of climatic suitability, and much of the loss occurring in these hazard zones is the result of beetles emigrating from high-hazard stands at lower elevations.

Stands were selected at random from suitable candidate stands within the zone of climatic suitability for MPB, using a table of random numbers. Stands ranged in infestation history from no recent infestation to those that had just completed an outbreak. Stands that had recently (within the past 10 years) been disturbed by human activity or wind were avoided. Stands that had other species present were sampled, as long as they had 75 percent or more lodgepole pine.

Each stand was sampled, using a 10-BAF variable plot cruising method. Ten plots located 5 chains apart on two lines located 5 chains apart (five plots per line) were used in each stand. However, in the case of odd-shaped stands, plots were located in any pattern that maintained spacing. The following data were recorded for each plot: (1) elevation; (2) habitat type; (3) slope; (4) aspect; (5) diameter at breast height (5 inches and larger) and species of tree; (6) alive or dead; (7) year tree killed (current year: tree green, fresh beetle attacks; 1 year old: most foliage retained and bright orange; 2 years old: one half or more foliage retained and dark brownish orange; older than 2 years); (8) pitch-outs and strip attacks; (9) other insect, disease, or mechanical injury; (10) two increment cores 180 degrees apart; (11) from each bored tree: height, crown length, crown class, sapwood depth, phloem thickness (green trees only); and (12) stand stocking.

Multiple regression analysis was used to determine which variable or set of stand variables best predicted lodgepole pine losses to MPB by broad geographic area. Only variables with F probability of 0.15 or less were considered. Variables included in the regression were: (1) basal area, (2) trees per acre, (3) quadratic mean diameter, (4) stand density index, (5) phloem thickness, (6) basal area of trees having phloem $\geq$ 0.10 inch, (7) age, (8) radial growth during last 5 years, (9) radial growth during previous 5 years, (10) sapwood thickness, (11) number of growth rings in last centimeter, (12) grams of wood per square meter of foliage in killed

trees, (13) grams of wood per square meter of foliage in uninfested trees, (14) elevation, and (15) latitude. Stands that had no mortality attributable to MPB were excluded from the analyses. Additionally, seven stands were selected for multiple regression (maximum R^2 procedure) of within-stand factors. However, because of the small sample of increment cores per plot, reliable estimates for variables related to tree growth could not be calculated for individual plots. The dependent variable used was percent of trees killed by MPB. Independent variables were: (1) measures of density, consisting of trees per acre (TPA), basal area (BA), and stand density index (SDI); and (2) measures of tree size, consisting of average diameter for trees $\geq$ 5 inches d.b.h. (AVGD), quadratic mean diameter for trees $\geq$ 5 inches d.b.h. (QMD), and percent of lodgepole 5 to 6.9 inches d.b.h. (%5-6.9). The seven stands were selected on the basis that (1) the current MPB infestation was almost completed, as indicated by current MPB activity, and (2) each stand was in a different National Forest.

GEOGRAPHICAL DIFFERENCES

One of the main objectives of a test of hazard rating methods was to determine if there were strong geographical influences. Stepwise multiple regression was used to determine which variables were most clearly associated with percent cumulative tree mortality by area--Central Rockies, Northern Rockies, and Pacific Northwest. The Central Rockies included the Gallatin National Forest and all National Forests south to Colorado. The Northern Rockies included all remaining National Forests in Montana, northern Idaho, and eastern Washington. The Pacific Northwest includ-ed the remaining National Forests in Washington and all National Forests in Oregon. In the stepwise procedure, variables that were not significant at the 0.15 level were excluded.

In the Central Rockies, the stepwise procedure showed cumulative lodgepole pine mortality was significantly related to two variables, latitude (F probability 0.016) and trees per acre (F probability 0.069). Cumulative mortality was negatively related to both of these factors. The negative relationship to latitude suggests decreased mortality occurs going north from Colorado to southern Montana. The decrease in mortality as latitude increases is probably an artifact related to when beetle infestations occurred. More recent MPB outbreaks have occurred in parts of Colorado and in northeastern Utah, whereas MPB populations farther to the north in the Central Rockies have been low for many years, following earlier outbreaks in the 1960's and 1970's. Past observations show tree mortality was high in the Bridger-Teton, Targhee, and Gallatin National Forests (Amman and Baker 1972; McGregor 1978). Most of these dead trees have been harvested or have fallen down. Therefore, we consider the relationship of less mortality with increased latitude within the Central Rockies to be false. The inverse relationship of mortality with trees per acre is consistent with past observations (Amman 1978), where heaviest tree losses occurred in less dense stands that contained a high percentage of large-diameter trees.

The stepwise procedure for data from the Northern Rockies also showed two variables having F probabilities less than 0.15--phloem thickness (F = 0.077) and stand density index (F = 0.097). Both were inversely related to cumulative tree mortality. Phloem thickness has in the past been related positively with MPB brood production (Amman 1972). However, once the MPB in the Northern Rockies build up to large numbers, they appear to overwhelm most trees. In many stands, the few remaining live trees on which to measure phloem are usually small-diameter trees that have thin phloem. The inverse relationship of cumulative mortality to SDI is consistent with the findings of Anhold and Jenkins (1987) and with increased mortality as trees per acre decline, as noted for the Central Rockies. Anhold and Jenkins (1987) found generally that mortality was greatest at SDI values between 125 and 250, having losses up to 90 percent at SDI 150. Tree losses in stands having SDI values of 90 to 125 were up to 20 percent. An SDI of 125 corresponds to crown closure, and an SDI of 250 corresponds to the beginning of full site occupancy (McCarter and Long 1986). Anhold and Jenkins (1987) suggested that trees in stands with an SDI above 250, even though of large diameter, would have thinner phloem and thus have less potential for producing beetles. Stands having SDI values below 125 could produce more resin to repel beetle attacks. Recent observations of tree vigor and microclimate in thinned and unthinned lodgepole stands suggest that microclimate plays an important role in reduced infestation of lightly stocked stands (Amman and others 1988; Bartos and Amman 1989).

In the Pacific Northwest, as in the other geographic areas, only two variables had F probabilities less than 0.15--grams of wood per square meter of foliage in killed trees ($P < 0.112$) and elevation ($P < 0.038$). Cumulative tree mortality was positively related to grams of wood. Increased tree mortality, with an increase in grams of stem wood produced per square meter of foliage, is opposite of observations by Waring and Pitman (1980) in Oregon. Therefore, additional work, particularly within stands, needs to be done to verify the relationship of grams of stem wood to tree mortality. Trees producing high wood-to-foliage ratios were just as likely to be infested as those producing lower wood-to-foliage ratios in the Central (Amman 1985) and Northern Rockies (Amman and others 1988). The inverse relationship of tree mortality to elevation is consistent with observations in southeastern Idaho and northwestern Wyoming (Amman and Baker 1972), and in northern Utah (Amman and others 1973). As elevation increases, weather is generally cooler and the MPB life cycle becomes delayed and out of synchrony with weather conditions for best brood survival (Amman 1973; Reid 1962).

WITHIN-STAND DIFFERENCES

When analyzing data obtained over a large geographic area, unexplained variance tends to be large. Therefore, the seven selected stands were analyzed to determine which of six variables explained the largest amount of variance in cumulative tree mortality within each stand.

The variable accounting for the greatest amount of variance in the percent of lodgepole pine mortality differed by stand. Measures of density were strongest in three of the stands--TPA in one, BA in one, and SDI in one. Measures of tree diameter were strongest in four stands--percent of trees 5 to 6.9 inches d.b.h. in one, QMD in two, and AVGD in one. The largest amount of variance explained by the regressions of individual factors within individual stands ranged between 9.4 and 68.6 percent (table 1). In multivariable models, variance explained in two variable models ranged between 34.5 and 79.9 percent; three-variable models ranged between 44.8 and 84.3 percent; four variable models ranged between 45.3 and 86.7 percent; five-variable models ranged between 60.5 and 95.4 percent, and six-variable models between 59.3 and 96.8 percent (table 2).

Going from the broad areas (Pacific Northwest, Northern Rockies, and Central Rockies) to the individual stand, much of the variance associated with the broad areas is eliminated and a much better prediction of mortality can be obtained. Tree size (QMD and AVGD) was positively correlated with tree mortality in five of the seven stands. This is consistent with observations that MPB show preference for lodgepole of large diameter (Cole and Amman 1969; Hopping and Beall 1948). These are the trees in which reproductive success is best (Amman 1969; Cole and others 1976; Reid 1963), probably because of generally thicker phloem, the food of developing larvae (Amman 1972), and greater moisture retention during beetle development (Cole and others 1976). Stand density (BA, TPA, SDI) was negatively correlated to tree mortality in five of the seven stands and always opposed (negative or positive) correlations with tree size. As basal area and SDI increase, tree competition increases and phloem thickness declines, thus beetle production declines. This is consistent with Anhold and Jenkins (1987), except at SDI values below 100, where high mortality occurred in our observations. Although SDI is made up of tree size and stand density, it often appears as a significant variable with BA and QMD. The percent of trees 5 to 6.9 inches d.b.h. is that portion of the stand that is not very susceptible to beetle infestation. Tree mortality was negatively correlated with trees 5 to 6.9 inches d.b.h. in five of the seven stands. Of the two positive correlations, one occurred when mortality was negatively correlated with stand density but positively correlated with tree size, and the second occurred under opposite conditions. When trees are infested in these diameters, few beetles are produced, on the average, resulting in a population deficit.

Although there are additional factors that will be explored for use in predicting lodgepole pine mortality when stands have been revisited and radial growth measures completed, these analyses suggest that a good combination may consist of a measure of (1) tree size (QMD), (2) stand density (BA), (3) percent of trees 5 to 6.9 inches d.b.h., and (4) an SDI that integrates tree size and stand density.

Terry Shore (these proceedings) has already progressed into assessing the performance of individual hazard rating methods in British Columbia. The next step in hazard rating analyses in western United States is to revisit plots to record any additional mortality and then test all existing methods and any new combinations, such as those in this paper. Until these tests are completed, managers should feel safe in using lodgepole pine diameter and a measure of climatic suitability to assess stand susceptibility to MPB (Amman and others 1977; Cole and McGregor 1983; Safranyik and others 1974).

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Table 1--Proportion of variance in percent tree mortality caused by mountain pine beetle (dependent variable) explained by different combinations of tree and stand factors

	National Forest							
Independent variable	Flathead	Lolo	Colville	Kootenai	Deschutes	Freemont	Winema	Forests combined
One-variable model:								
Trees per acre	0.438	0.266	0.018	0.183	0.071	0.023	0.369	0.0064
Basal area	0.061	0.223	0.094	0.066	0.008	0.001	0.454	0.00001
Stand density index	0.171	0.237	0.070	0.100	0.021	0.002	0.501	0.0003
Percent trees 5-6.9 inches DBH	0.534	0.061	0.054	0.299	0.111	0.289	0.001	0.058
Quadratic mean DBH	0.223	0.011	0.006	0.331	0.686	0.005	0.245	0.077
Average DBH	0.243	0.004	0.016	0.330	0.674	0.012	0.170	0.082

Table 2--The best one- to six-variable models based on maximum R^2 procedures

	National Forest															
	Flathead		Lolo		Colville		Kootenai		Deschutes		Freemont		Winema		Forests combined	
Number of variables	Model	R^2	Model	R^2	Model	R^2	Model	R^2	Model	R^2	Model	R^2	Model	R^2	Model	R^2
1	[1]%5-6	0.534	TPA	0.266	BA	0.094	QMD	0.331	QMD	0.686	%5-6	0.289	SDI	0.501	AVGD	0.082
2	[2]%5-6 BA	0.652	TPA %5-6	0.365	BA SDI	0.345	QMD %5-6	0.423	QMD TPA	0.799	%5-6 AVGD	0.540	BA AVGD	0.534	AVGD TPA	0.098
3	%5-6 SDI TPA	0.722	%5-6 TPA QMD	0.518	BA SDI %5-6	0.672	%5-6 QMD AVGD	0.448	AVGD %5-6 SDI	0.843	%5-6 AVGD QMD	0.626	QMD BA SDI	0.555	AVGD SDI BA	0.126
4	%5-6 TPA SDI BA	0.749	BA %5-6 QMD AVGD	0.529	AVGD QMD BA SDI	0.829	%5-6 QMD AVGD TPA	0.453	%5-6 BA AVGD QMD	0.867	%5-6 AVGD QMD TPA	0.647	QMD BA SDI TPA	0.582	AVGD BA SDI TPA	0.152
5	SDI BA QMD AVGD TPA	0.871	TPA SDI BA AVGD %5-6	0.954	AVGD QMD BA SDI TPA	0.908	%5-6 BA SDI TPA AVGD	0.566	TPA SDI BA AVGD QMD	0.886	%5-6 AVGD QMD SDI BA	0.651	AVGD BA SDI TPA %5-6	0.605	BA SDI TPA AVGD QMD	0.152
6	QMD AVGD BA SDI TPA %5-6	0.871	BA SDI TPA AVGD %5-6 QMD	0.968	AVGD QMD BA SDI TPA %5-6	0.924	%5-6 TPA SDI BA AVGD QMD	0.593	AVGD BA QMD TPA SDI %5-6	0.910	%5-6 AVGD QMD BA SDI TPA	0.655	BA SDI TPA AVGD %5-6 QMD	0.613	BA SDI TPA AVGD QMD %5-6	0.152

[1]Abbreviations stand for the following: %5-6 = percent of lodgepole in the 5 to 6.9-inch d.b.h. class; TPA = number of trees per acre; BA = square feet of basal area, all tree species; SDI = stand density index; QMD = quadratic mean d.b.h. of all lodgepole; AVGD = average d.b.h. of all lodgepole 5 inches and larger d.b.h.

[2]Variables in multivariable models are listed from most to least significant.

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A PRELIMINARY EVALUATION OF HAZARD RATING SYSTEMS FOR THE MOUNTAIN PINE BEETLE IN LODGEPOLE PINE STANDS IN BRITISH COLUMBIA

Terry L. Shore, Paul A. Boudewyn, Eleanor R. Gardner and Alan J. Thomson

ABSTRACT: Five hazard rating systems were evaluated for 59 lodgepole pine stands that had experienced mountain pine beetle epidemics. None of the methods was found to satisfactorily predict the amount of mortality which would occur as a result of the beetle. We feel the primary source of variation inhibiting proper analysis of these methods is a measure of beetle population pressure, and that a risk model which incorporates both stand hazard and beetle population pressure, such as proposed by Paine and others (1984), would better describe stand risk to the mountain pine beetle.

INTRODUCTION

A number of systems have been proposed for rating the hazard of lodgepole pine stands to mountain pine beetle (MPB) damage. A reliable hazard rating system would allow forest managers to prioritize stands for harvesting or treatment. The performance of some of these hazard rating systems in various forest types has been discussed previously in a number of papers (Mahoney 1978; McGregor and others 1981, 1986; Amman 1985; Shrimpton and Thomson 1983, 1985; Stuart 1984; Katovich and Lavigne 1985). In 1982, as part of the Canada-United States Mountain Pine Beetle / Lodgepole Pine Agreement it was decided to evaluate six hazard rating systems (Safranyik and others 1974,1975; Amman and others 1977; Mahoney 1978; Berryman 1978; Schenk and others 1980; Waring and Pitman 1980) over a large number of lodgepole pine stands throughout the range of the beetle in order to identify the best possible system for a given region or forest type. This paper reports our early findings on five of the systems for stands in the Cariboo Region of British Columbia.

The terms hazard and risk are often used interchangeably or interpreted differently. We define risk as the probability of an infestation starting in a given stand. Hazard is a measure of the characteristics of a stand that affect its susceptibility to the MPB once it is under attack.

Paper presented at the Symposium on the Management of Lodgepole Pine to Minimize Losses to the Mountain Pine Beetle, Kalispell, MT, July 12-14, 1988.

Drs. Shore and Thomson are Research Scientists, Ms. Gardner is a Forest Officer and Mr. Boudewyn was formerly a Technician at the Pacific Forestry Centre, Canadian Forestry Service, Victoria, B.C.

In British Columbia, forest land covers approximately 116 million acres (47 million ha). Almost 25% of the volume harvested currently is in lodgepole pine. In the Cariboo Forest Region approximately half the volume harvested is lodgepole pine (Anon. 1986). Since 1972 when the MPB infestation began in the western part of the region, millions of trees have been killed over hundreds of thousands of acres resulting in serious disruption of the timber supply.

METHODS

Fifty-nine stands were sampled in the Cariboo Forest Region based on 10 prism plots (BAF 10-english units) spaced at 328 foot (100 m) intervals. Species and diameter at breast height (DBH) were recorded for all sample trees and two increment cores taken at 180^{0} from each of three sample trees in each plot. Phloem thickness was measured in the field while sapwood width, age and yearly increments were measured in the laboratory with a Measuchron tree ring measuring device linked to a VAX computer. Following the collapse of the MPB infestation in the Cariboo, these stands were revisited and plot trees killed by the MPB were recorded.

RESULTS

In the sample stands the species mix ranged from 60-100% lodgepole pine with Douglas-fir, white spruce and trembling aspen being the most commonly associated species. Stand age was primarily mature and overmature, stand density ranged from 137 to 595 trees per acre (338 to 1,470 per ha) and average stand diameter ranged between 5.5 and 12.5 inches (14 and 32 cm).

Analysis of Hazard Rating Methods

Amman and others 1977--This method involves rating elevation-latitude, mean stand DBH of lodgepole pine and mean stand age each on a scale of 1-3 according to established thresholds. The product of these three ratings gives the stand hazard, which is interpreted in terms of the percentage mortality to lodgepole pine trees greater than 8.5 inches DBH as follows: 1-9 low hazard (< 25% of trees), 10-18 moderate hazard (25-50% of trees), and 27 high hazard (> 50% of trees). There is one exception; if all three values are moderate (i.e. 2 x 2 x 2) the value 8 is considered to represent moderate hazard. This means there are 19 ways to get a low hazard, seven ways to get a moderate hazard and only one way to get a high hazard.

Of the 59 stands, mortality was estimated correctly in 14 stands (24%)(Table 1). Most of the error involved rating stands as moderate when low mortality occurred. Of 32 stands rated moderate only three were correctly identified. When the stands with no mortality were removed from the analysis only 8% of the low mortality plots were predicted correctly (Table 1).

Table 1—Observed and predicted tree mortality based on the system of Amman and others (1977)(see text for definitions)

	Low	Moderate	Severe	Total
Observed	41 (25)	4	14	59 (43)
Predicted	13	32	14	59
Correct	8 (2)	3	3	14 (8)
% Correct	20 (8)	75	21	24 (19)

Numbers in parentheses refer to stands experiencing some tree mortality by MPB.

Mahoney 1978—This method is based on the Periodic Growth Ratio (PGR) which is calculated as the current 5 year radial increment divided by the previous 5 year radial increment of dominant and co-dominant lodgepole pine trees. A PGR of less than 0.9 would indicate declining vigor and increased susceptibility to MPB resulting in greater than 10% tree mortality for trees greater than 5 inches (12.5 cm) DBH, whereas PGR greater than 0.9 would indicate a vigorous stand that is resistant to MPB. In this case expected mortality would be less than 10% of trees 5 inches DBH. Mahoney limited the application of his method to stands with favourable climate, average tree age greater than 60 years and average diameter greater than 7 inches (17.5 cm).

Of the 46 eligible stands, 23 (50%) were predicted correctly, which in a two class system is what would be expected by chance. The method was more successful at predicting low mortality than high mortality (Table 2). When stands with no mortality were removed from analysis 72% of the low mortality stands were predicted correctly.

Table 2—Observed and predicted tree mortality based on the system of Mahoney (1978)

	Low(<10%)	High(>10%)	Total
Observed	33 (18)	13	46 (31)
Predicted	30	16	46
Correct	20 (13)	3	23 (16)
% Correct	61 (72)	23	50 (50)

Numbers in parentheses refer to stands experiencing some tree mortality by MPB.

Schenk and others 1980—This method uses crown competition factor (CCF), a measure of stand density (Krajicek and others 1961), and the proportion of the stand basal area represented by lodgepole pine (PLPBA) to calculate a stand hazard rating (SHR) as:

$$SHR = CCF\ (PLPBA/100)$$

The SHR is then related to mortality, in terms of the percentage of lodgepole pine basal area killed (%BAK) by the beetle.

We found that %BAK was inversely related to CCF (Fig.1). A similar finding was reported by McGregor (and others 1981;1986). Figure 2 shows the relationship between %BAK and SHR and the fit of one possible model to this relationship. Although there are no data at SHR less than 0.45 it is reasonable to assume that %BAK drops to zero at very low stand densities or percentage pine component (Fig. 2). This model suggests that MPB-caused mortality decreases with increased stand density through most stands rather than increases as hypothesized by Schenk and others (1980).

Berryman 1978—This method uses the ratio of PGR/SHR as a measure of Stand Resistance, and the percentage of the lodgepole pine basal area having phloem thicker than 0.1 inch (2.5 mm) as a measure of a stand's ability to support a beetle population.

The percentage of stand basal area with phloem greater than 0.1 inch did not appear to be a relevant factor in the model (Fig. 3). There was some separation between severely damaged stands (greater than 40% tree mortality) and the low and moderate mortality classes, but very little separation between the latter two. However, the greatest mortality occurred at the highest level of resistance (Fig. 3). This reversal is probably due to the inverse relationship found between mortality and SHR, on which Berryman's method is partially based.

Waring and Pitman 1980—This method involves calculating Growth Efficiency as the ratio of current growth (grams of stemwood produced) to crown leaf surface. These values are obtained through relationships to basal area increment and sapwood basal area (Mitchell and others 1983). Trees producing less than 50 g of wood per m^2 foliage are highly susceptible, trees producing 51 to 100 g are moderately susceptible, and trees producing more than 100 g are highly resistant to MPB attack (Amman 1983). The highest Growth Efficiency found in our study was around 60 which would indicate that the majority of stands were highly susceptible (Fig. 4). There appeared to be no direct relationship between the amount of mortality and Growth Efficiency within the range of values found in this study (Fig. 4).

DISCUSSION

None of the five methods examined provided a useable system for hazard rating stands. The PGR system (Mahoney 1978) may be theoretically unsound because PGR should tend to decline at a tree age of about 30 years (Shrimpton and Thomson 1981), and because it does not differentiate between fast and slow growing trees (McGregor and others 1981; Katovich and Lavigne 1986). The underlying hypothesis in the SHR method (Schenk and others 1980) appears to be the reverse of what is found in the field. However, it should be noted that CCF and SHR are significantly related to tree mortality and therefore should be integral components of a hazard rating system. Berryman's method (Berryman 1978), being based on

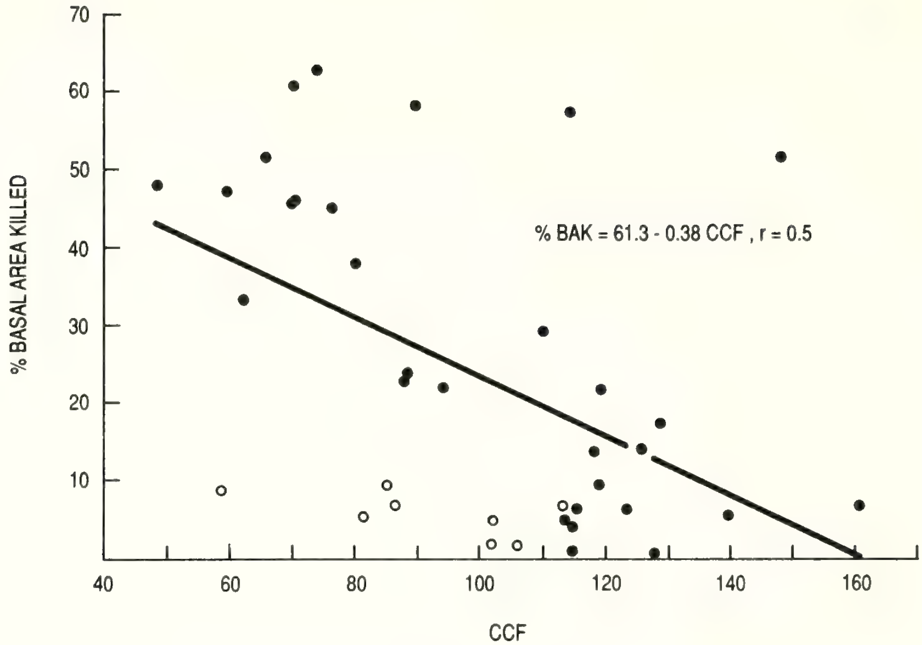

Figure 1—The inverse relationship between percentage of lodgepole pine basal area killed by mountain pine beetle and crown competition factor (CCF) (Krajicek and others 1961).

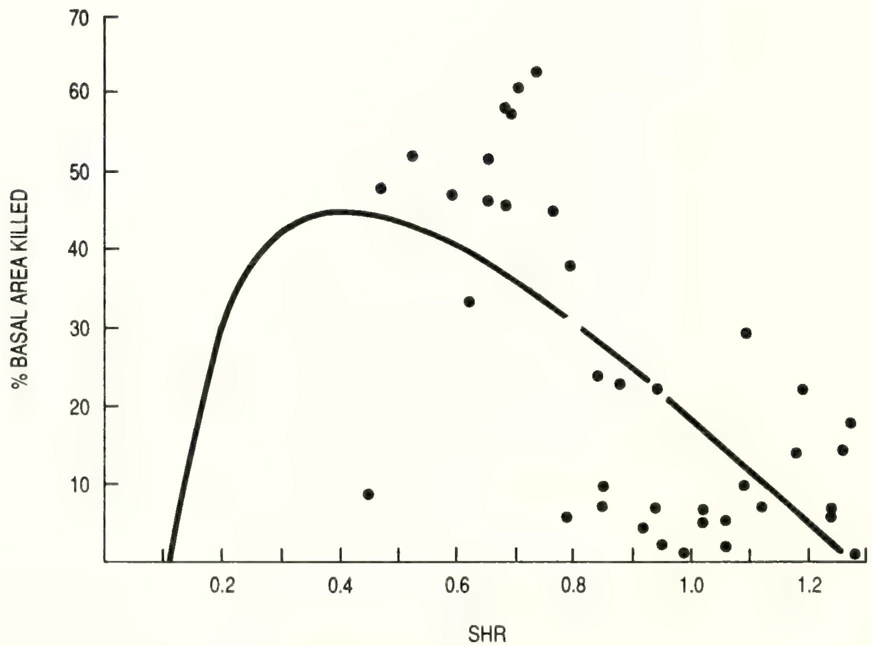

Figure 2—A fit of the model Y=a+b/X+cX to the relationship between percentage lodgepole pine basal area killed and Stand Hazard Rating (SHR) as defined by Schenk and others (1980); a=106.5, b=-12.27, c=-75.73, r=0.67.

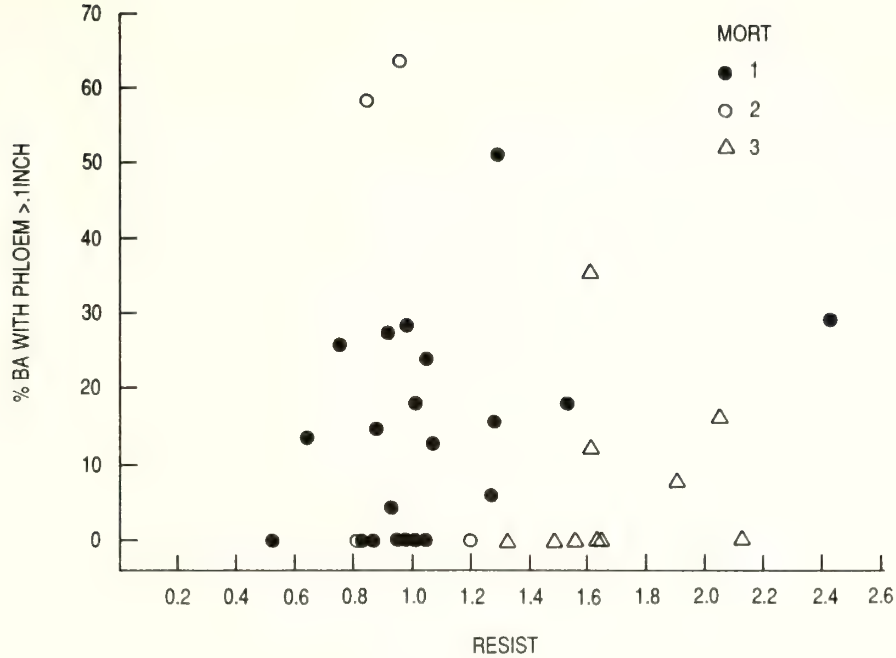

Figure 3—Mortality classes as a function of the percentage of basal area having phloem greater than 0.1 inch (2.5 mm) and resistance (Berryman 1978); 1 = ‹ 11%, 2 = 11 - 40 %, 3 = › 40 % of lodgepole pine basal area killed.

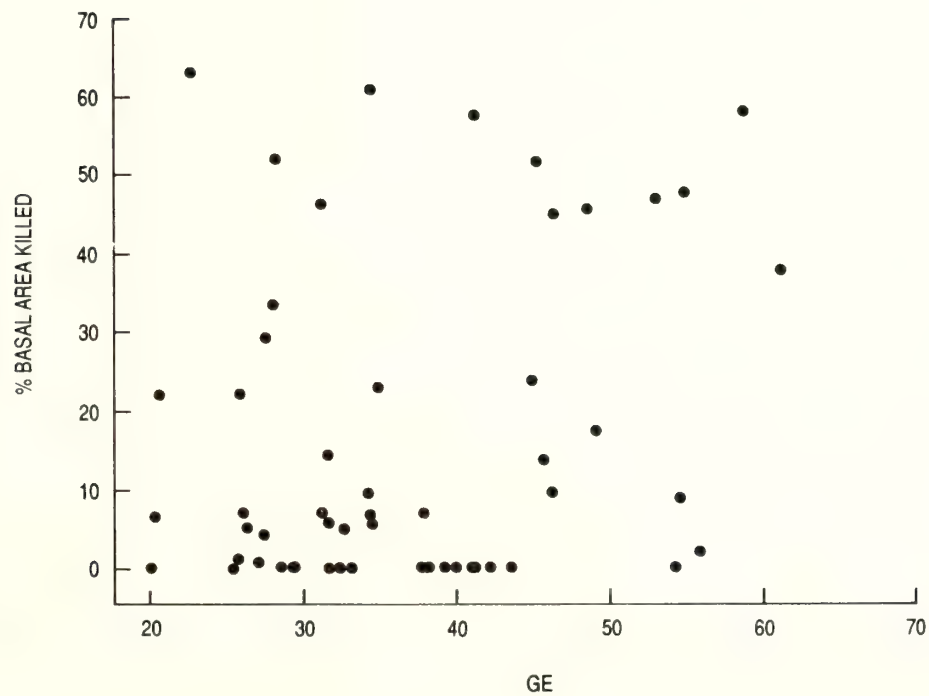

Figure 4—The relationship between percentage basal area killed and growth efficiency (GE) (Waring and Pitman 1980).

PGR and SHR suffers from the problems inherent in those methods as well as from an apparently insignificant relationship between percentage of basal area having phloem greater than 0.1 inch and mortality. While we know that MPB shows a preference for larger diameter trees, and produces more and larger brood in thicker phloem, phloem thickness is poorly related to DBH (Shrimpton and Thomson 1985). The Growth Efficiency method (Waring and Pitman 1980) successfully predicted that the majority of stands were highly susceptible. However, the system does not provide a measure of expected mortality which limits its usefulness. The poor results obtained with the system of Amman and others (1977) may be due to differences in the threshold values of the component variables in the British Columbia forests. A problem with most of the systems is that they do not account for variability due to MPB population pressure.

To evaluate the probability of a given stand being attacked and sustaining damage it is necessary to know both the susceptibility of the stand to MPB damage and the probability of a MPB population entering the stand. The conceptual model proposed by Paine and others (1984) states that risk is a function of hazard and population pressure. We agree with this concept. The hazard rating methods so far have concentrated on determining stand susceptibility. However, if variability due to population pressure is not accounted for there will always be a poor relationship between stand hazard and damage. A stand can be highly susceptible to MPB but if there is no population in the area it is at low risk. Conversely, a stand of relatively low susceptibility can receive more than its expected level of damage if it is in the path of a raging epidemic. By including both indicators of beetle population pressure and stand hazard, a dynamic estimator of stand risk can be calculated on an annual or periodic basis. To develop the best hazard rating method, the most promising indicator variables should be compared for stands experiencing similar MPB population pressure.

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CASE HISTORY: APPLICATION OF RISK ASSESSMENT--FLATHEAD NATIONAL FOREST

Paul R. Beckley

ABSTRACT: In 1978, personnel of the Tally Lake Ranger District, Flathead National Forest, MT, initiated a risk assessment process and revised lodgepole pine harvest program to combat a potential mountain pine beetle epidemic. The epidemic was extensive by 1985. The INDIDS mortality model became available and was run for every stand. To consolidate information, a data base called X-BEETLE was developed. Assumptions were largely correct and risks taken paid dividends. Success in managing a large epidemic depends on sound information and ability to analyze it properly.

INTRODUCTION

Mountain pine beetle populations have existed in an endemic condition for many decades in the Flathead National Forest. It was only a matter of time until extensive lodgepole pine stands originated by fire acquired the characteristics necessary to generate a mountain pine beetle epidemic. The following is a summary of how one ranger district in the Flathead National Forest anticipated, prepared, and successfully dealt with a major epidemic of mountain pine beetle.

EPIDEMIC SITUATION

Around 1978 it became evident that the vast mature lodgepole pine stands in the Tally Lake District of the Flathead National Forest had reached conditions conducive to a major mountain pine beetle epidemic. The district was obviously sitting on a volatile situation that needed immediate attention. Mountain pine beetle populations had already increased to epidemic levels in the Gallatin National Forest and new epidemics were developing in parts of the Beaverhead, Kootenai, and Lolo National Forests. The situation close to home was just as bad if not worse. Epidemic levels were reached in the Glacier View Ranger District of the Flathead National Forest in 1975 with about 80 acres infested. By 1978 this had increased to 80,000 acres. An infestation in Glacier National Park increased from 1,180 acres in 1972 to 165,000 acres in 1978. This combined to almost 225,000 acres, which presented a formidable threat to the Tally Lake District. At the same time the Tally Lake District continued to show surprising resistance to attack with only scattered small activity centers throughout the district.

ORIGINAL PLANNING EFFORTS--PHASE I

Considering the large potential for resource losses in the Tally Lake Ranger District as well as other nearby districts, it was decided that an accelerated harvest program concentrating on high-risk lodgepole pine should be attempted. In July 1978 the Tally Lake District decided to inventory and evaluate all lodgepole pine stands for their susceptibility to mountain pine beetle. The system used to determine risk was based on that developed by Amman and others in 1977. The rating was based on average tree diameter, age, and elevation. From this survey it was estimated that approximately 38,000 acres and 320 million board feet of high-risk lodgepole existed in the Tally Lake District.

In October 1978 the Flathead National Forest held an interagency and industry meeting to establish the Northwest Montana Mountain Pine Beetle Task Force. It was the function of this group to develop alternative strategies for coordinated management of the mountain pine beetle hazard. The resulting direction was finalized in early 1979 and was documented in an environmental assessment report.

One of the major purposes of the mountain pine beetle harvest program was to capitalize on the economic differential between green and dead lodgepole pine. This differential was substantial at that time. The basic structure of the harvest program was to:

- Substitute lodgepole pine harvest for other species.
- Harvest one half of high-risk lodgepole over a 3-year period (160 MMBF).
- Shift the majority of the forest harvest to the Tally Lake Ranger District and not change the forest total.
- Emphasize preroading of high-risk lodgepole pine stands with the use of capital investment funds.

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Paul R. Beckley is former District Silviculturist for the Tally Lake District, Flathead National Forest, Whitefish, MT. Presently Forest Economist, Flathead National Forest, Kalispell, MT.

-Reevaluate epidemic status and management direction in 1982 (Phase II). The assumption was that the epidemic would be well under way by 1982 and the program would evolve to one of sanitation-salvage harvesting rather than regeneration harvesting of green stands.
-The resulting 1980-1982 timber sell and harvest levels can be seen in table 1. This includes all species including lodgepole pine for a total sell program of 230.9 MMBF over a period of 3 years.

Table 1--Timber volume sold and harvested--Tally Lake District, Flathead National Forest

Fiscal Year	Timber Sold(MBF)	Timber Harvested (MBF)
1975	37.6	25.6
1976	24.8	31.5
1977	44.3	54.2
1978	11.1	22.5
1979	10.7	18.9
1980	136.2	27.4
1981	32.4	38.2
1982	62.3	16.2
1983	27.2	29.7
1984	20.7	57.5

REPLANNING--PHASE II

As previously mentioned, a reevaluation was planned in 1982 to determine if any planning revisions would be necessary. Several situations that were originally assumed in Phase I did not materialize. The first and most important assumption was that the epidemic had not developed as expected. The mountain pine beetle status in the Tally Lake District was still of endemic proportions. Another unexpected event was that the timber sales that were being sold were not being harvested because of a poor lumber market. Because of these unexpected events, it was decided that any replanning would be postponed. However, in 1983 significant mortality in lodgepole pine began to occur. An even more spectacular buildup occurred in 1984 and by 1985 the entire south end of the Tally Lake District was in an epidemic situation. With this new development, Phase II planning began.

In this same general time period several other things were developing that would be of great assistance in future planning. These were:
-Silvicultural examinations had been completed for the entire Tally Lake District.
-Several silvicultural and chemical techniques were being developed to decrease the impact of mountain pine beetle.
-The Data General computer system along with a powerful data base and report writing software was being installed throughout the Forest Service.
-The INDIDS mountain pine beetle mortality model was being developed.

We also recognized by this time that it would be extremely helpful to have a data base system that could isolate lodgepole pine from other species. The existing timber stand management record system did not separate lodgepole from other species.

Another important point to recognize was that the probability of an epidemic in any particular stand was no longer a variable. It was safe to assume that there was 100 percent probability that all stands would eventually be affected. The only question was how much could we expect to lose from each stand and how we should use this information as the primary criterion for prioritizing stands for harvest.

It was felt that the INDIDS mountain pine beetle mortality model could provide us with the necessary information to make management decisions. The model basically:
-Predicts the lodgepole pine mortality for each year of an epidemic from beginning to end and gives total predicted volume losses for each individual stand.
-It is designed to run directly from stand examination data files (R-1 Edit).

The INDIDS model was run for every stand in the Tally Lake District that contained lodgepole pine. To bring all this new information together it was obvious that it would be useful to develop a data base to hold the applicable information and present it in a format that made it analyzable. With this in mind we designed a data base called X-BEETLE. It is a Data General data base interfaced with a Data General report writer program called PRESENT. By entering key mortality items from the INDIDS output along with a few stand exam data items the following report information could be generated:
-Stand identification
-Stand acres
-Preepidemic stand characteristics
-Postepidemic characteristics
-Equivalent clearcut acres

The stand characteristics are described in terms of MBF/acre, cubic ft/acre, basal area/acre, and total stand MBF.

The standard programs for X-BEETLE have been designed to produce the following reports:
-Stands may be listed in order of stand identification number. The report may include all stands in a ranger district, all stands in a particular compartment, and combinations of compartments or subcompartments. It may also list any combination of individual stands. This has proven to be extremely useful in designing alternatives for analysis.
-Stands may be listed in order of predicted losses in terms of

MBF/acre. They may also be limited to those areas discussed above.
- The report may also be designed to list only stands with predicted losses greater than 10 MBF/acre, 5 to 10 MBF/acre, and less than 5 MBF/acre.
- A report can be generated to produce only totals for specified areas.

The generation of equivalent clearcut acre (ECA) information has proven extremely useful for those areas where increased water yield may be a limiting factor for planned activities. This information predicts the estimated impact of a mountain pine beetle epidemic on increased water yield. It is especially helpful in determining the hydrologic impact of no action or deferred action alternatives. The data are generated by a linear equation based on a reduction in basal area once a certain threshold has been exceeded.

To visually perceive the spatial pattern of predicted mortality, it was decided that mapping should be done. Stands were divided into three categories based on predicted mortality. This was done on TSMRS compartment maps for the entire district. This function can now be done automatically with the multilevel resource information system (MURIS).

With this new information it was decided that the future strategy on the Flathead National Forest would be based on the following assumptions:

- Revert back to the preepidemic sale level of 30 MMBF/year.
- Epidemic will have run its course in the next 5 years or at least 85 percent of the predicted mortality will have occurred.
- Basic district management philosophy will not change.

Based on these assumptions the district strategy will be:

- Two thirds of the annual sale program will be concentrated in stands where predicted lodgepole pine mortality exceeds 10 MBF/acre.
- An effort will still be made to maximize the green vs. dead value differential by harvesting ahead of mortality.
- One third of the program will harvest mortality and consist of other miscellaneous sales.
- After 4 years there will be a shift away from lodgepole pine and back to mixed species. However, an effort will be made to continue to harvest dead lodgepole with the small sales program.

CONCLUSIONS

The success in managing a large mountain pine beetle epidemic depends heavily on not only the information available but on one's ability to manage or analyze the information. Overall objectives should be fairly clear before data are gathered and analyzed. A manager should also feel comfortable in making important decisions based on probabilities. In the case of the Tally Lake District it was highly probable that a significant amount of lodgepole pine would be lost to mountain pine beetle and harvesting was based on this assumption. The assumptions turned out to be largely correct and the risks that were taken paid off significantly. However, much of the success has to be attributed to the ability of the district to realize the importance of the collection and management of appropriate information. This could not have been done nearly as efficiently as it was without the availability of the INDIDS mortality model or the X-BEETLE data base.

The INDIDS model proved to be slightly conservative in its mortality predictions for the Tally Lake District. However, it can be calibrated if desired to reflect local conditions.

As previously mentioned the primary purpose of preepidemic harvesting was to capitalize on the economic differential between green and dead timber. Another benefit that was assumed is that the epidemic effects may be reduced by removing stands of large-diameter lodgepole pine, thus reducing insect population growth. However, this did not occur because of: (1) the significantly delayed harvest of lodgepole pine because of poor market conditons and (2) the enormous beetle population.

In summary, it is obvious that all the anticipated losses of lodgepole pine cannot be harvested. For this reason prioritization is extremely important to maximize objectives. Therefore, it is important to determine what objectives actually are from the very beginning of the program and to design it to meet these objectives.

A TOOL FOR ASSESSING THE IMPACTS OF MOUNTAIN PINE BEETLE AND RELATED MANAGEMENT STRATEGIES

Merrill S. Davis and William B. White

ABSTRACT: The Forest Pest Management Methods Application Group of the U.S. Forest Service has developed an automated, menu-driven, Decision Support System that operates on Data General minicomputers and utilizes spatial data from a geographic information system, and information from tabular data bases, to run various resource simulation models. Developed to analyze and display the impacts of mountain pine beetle on resource values, this system has the potential for broad application in the analysis of impacts of most management practices on resource values.

INTRODUCTION

Natural Resource Management entails varied and complex problems which the resource manager must solve. Demands on resources come from many sources. These demands often involve an open and direct conflict of values. It is the unique job of the resource manager to evaluate and implement management strategies over time that protect long term resource values, while providing a mix of opportunities to meet resource demands.

Declining budgets and personnel ceilings complicate the job of the resource manager at a time when more informed publics and user groups are raising issues that require detailed analysis and assessment of cummulative effects. As more analysis and study are undertaken, additional constraints surface which require further evaluation and impose new considerations in the formulation of management alternatives.

Just when managers feel they have identified the best management strategy, along comes a destructive agent, such as mountain pine beetle, that affects resource conditions to the extent that management plans must be reevaluated.

Faced with budgetary and time constraints, and required by policy, Congress, and the courts to do a more thorough job of analysis, resource managers must become more efficient and timely in their ability to plan and execute management strategies that are responsive to changing resource conditions and changing public values.

One solution to the resource managers dilemma is better use of analytical capabilities and application of new and emerging technologies. There is a recently developed tool that can enable resource analysis to be completed more timely and efficiently and be displayed in a manner that will greatly aid the decisionmaker in choosing the best management alternative. This tool is a user friendly flexible system framework or shell that links a geographic information system and independent data bases with resource or impact models to estimate the effects of alternative courses of action. This system is known as INFORMS (Integrated Forest Resource Management System).

INFORMS displays the effects of a management activity on a resource value in tabular or graphic form. The structure of INFORMS is modular; this results in flexibility in application because only those models and data which are appropriate for a specific analysis are linked and used. The modular structure also allows model updates or models specific for a certain geographic location to be inserted without major programming changes to the basic INFORMS shell.

BACKGROUND

In 1984, the Nez Perce National Forest entered into a cooperative agreement with the Forest Pest Management Methods Application Group to develop and evaluate an automated decision dupport system to analyze the impacts of mountain pine beetle on resources on the Red River Ranger District. The primary role of the Forest in this project was to describe the current environmental analysis process, identify the resource models commonly used, and provide the spatial and tabular resource data needed for the analysis. Forest Pest Management's primary role was to provide the system design and programming expertise necessary to link the data bases and models together in a single, menu-driven system. In addition to FPM, several other groups cooperated in the development of INFORMS, including the Western Energy Land Use Team of the U.S. Fish

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Paper presented at the Symposium on the Management of Lodgepole Pine to Minimize Losses to the Mountain Pine Beetle, Kalispell, MT, July 12-14, 1988.

Merrill S. Davis is District Ranger, Butte Ranger District, Deerlodge National Forest, Butte, MT; William White is Acting Group Leader, Forest Pest Management, Methods Application Group, Forest Service, U.S. Department of Agriculture, Fort Collins, CO.

and Wildlife Service, and the University of Arizona. However, FPM has been the primary coordinator throughout the project. The Red River Ranger District is currently in their fifth year of the program and are in the process of writing a user's guide and written evaluation of the system.

In 1987, the Butte Ranger District of the Deerlodge National Forest was given the charter of testing the transferability of the INFORMS Decision Support System. The Butte Ranger District's responsibility is to test the transferability of INFORMS to another geographical location, refine existing resource models to fit their condition, and to test new models as they become available. The Butte District is evaluating the performance of INFORMS by using the system to develop an area analysis on 23,000 acres of National Forest. This analysis will prescribe management practices to be implemented within the analysis area over the next ten years. This analysis unit contains a Congressionally designated recreation area administered by City/County government, a municipal watershed, and a private inholding of 1,100 acres on which 45 families reside. The area is bordered by the interstate highway system and transected by a state highway system. There is an active infestation of mountain pine beetle that has moved into one corner of the analysis unit and is predicted to spread over most of the area. In addition, the analysis unit is in the background viewing area for the City of Butte. When INFORMS was under development on the Red River District of the Nez Perce National Forest, it was known as the Integrated Pest Management Assessment System (IPMAS). However, it became readily apparent that this decision support system had potential far beyond the original charter of assessing the impacts of mountain pine beetle on Forest resource values.

THE TOOL - INFORMS

The Integrated Forest Resource Management System (INFORMS) is a Decision Support System (DSS), aimed at improving the efficiency of resource data and simplifying the use of new technologies in natural resource management. INFORMS combines new and conventional information science technologies into an adaptable computer system environment or shell. Technologies such as advanced computers, spatial analysis functions, data bases (spatial and nonspatial), and simulation models are used.

INFORMS is written in FORTRAN 77 and runs on a Data General MV Series machine. In its present form the software is made up of four major system components (fig. 1). These are: Central Control Module, Model Library, Spatial and Non-spatial Components.

Central Control Module

The Central Control Module (CCM) is the primary component of INFORMS and operates as the logic engine of the system. CCM is the control panel of the user through which all components are linked. User requests are transformed into system commands to define the problem, perform analysis, and present results. The user interface to CCM is menu-driven, providing both text and high resolution graphic capabilities.

Model Library

The Model Library is a collection of programs (models) in files that simulate dynamics of various resources. These include:

PROGNOSIS - A stand growth and yield model that simulates the size and structure of Forest stands over time.

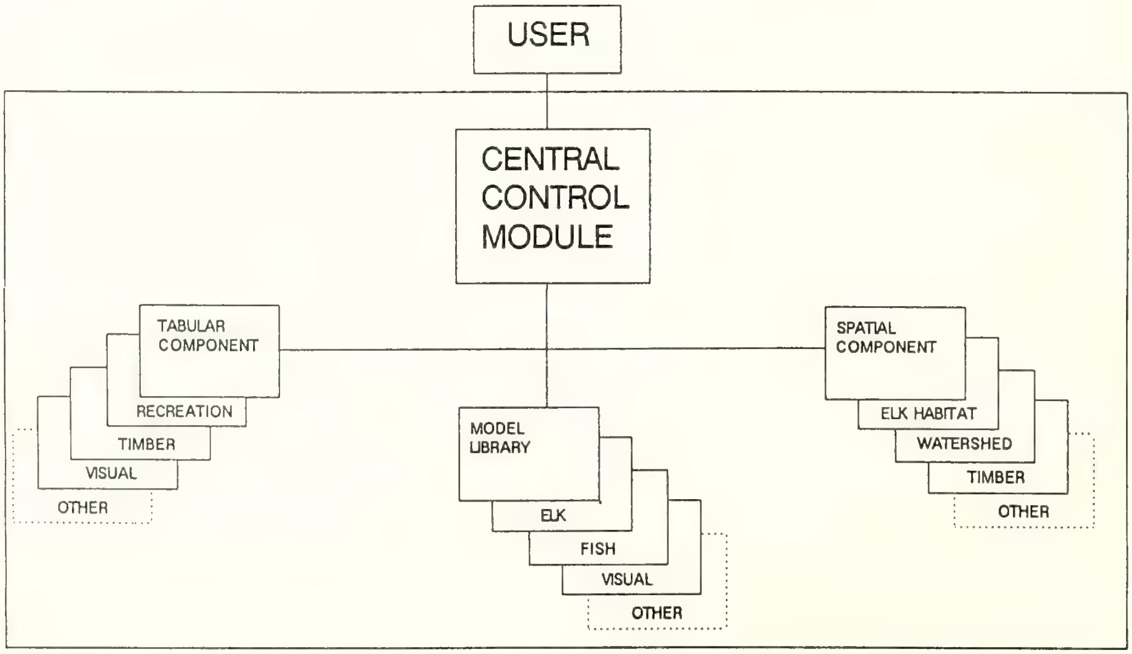

Figure 1.--Informs system diagram showing major components.

NEZSED - A sedimentation model that computes the amount of sediment delivered to critical stream reaches in response to fire occurence, logging, and road building.

FISH - A fisheries model that simulates the response of Brook and Cutthroat Trout to sediment loading in streams.

ELK - An elk dynamics model that identifies the effective security cover based on road use, and attributes of cover.

COVER - A cover model that simulates the growth and structure of wildlife cover over time.

CONTAGION - A dispersion model that projects the rate of spread and extent of mountain pine beetle caused damage.

DLOGPRICE - An econometric model that evaluates the viability of proposed timber sales.

VISUAL - A visual sensitivity model for evaluating aesthetic changes relative to management actions.

WATER YIELD - A water yield model that simulates water run-off in response to road building, logging, and fire occurance.

SBW HAZARD - An insect risk rating model that rates forest stand susceptibility to spruce budworm damage.

Spatial Component

This component contains the spatial functions for manipulating and displaying spatial data. These data are in the form of maps organized into various data themes, such as timber, watersheds, soil types, and roads. The number and type of themes are a function of the problem universal INFORMS is configured to solve. This map information is stored in the polygonal format utilized by the geographic information system - MOSS (Map Overlay and Statistical System). The spatial component also provides a direct link to MOSS so that the user may access the full functions of a general purpose GIS.

Nonspatial Component

Nongeographic data such as timber inventory data and economic data are retrieved from various data bases (local or remote) for input into the various models.

INFORMS resides on the U. S. Forest Service Data General minicomputer on site at the Butte Ranger District, Deerlodge National Forest, Butte, Montana. A high resolution graphics terminal is needed to take advantage of all INFORMS functions. Though not absolutely necessary, all the individual components of INFORMS are on the same computer.

APPLICATION

INFORMS aids the resource manager in the decisionmaking process on the timing, extent, and type of management strategies to be employed to minimize the loss from mortality associated with mountain pine beetle outbreaks.

Predictive Model

INFORMS embodies a predictive model (contagion) that uses stand data to project the rate of spread and the extent of mountain pine beetle damage. Resource managers can use this information to prioritize which analysis units should be analyzed first to prioritize when and where harvest activity should take place.

Scoping

Scoping is the process used to determine the extent of analysis necessary for an informed decision on any proposed activity.

INFORMS aids the scoping process by providing good displays of available resource information; maps of allocation areas, graphs and tabular data on present resource values, and maps and tabular data on predictive models. This professionally displayed information is very useful in informing publics of proposed activities, what resource values are present, and what course of action the mountain pine beetle is expected to take.

Having good information on the resource values within an area to be analyzed and being able to professionally display this information internally, with other agencies, and with interested publics, materially aids in the quality of the scoping process, and reduces the time required to complete this aspect of the process. Many potential or emerging issues can be defused.

Data Collection

Based on the issues and concerns, resource response or impact models are selected for use in the analysis. Model selection determines the amount and kind of data needed to conduct the analysis. Models indicate when data required is not in place and needs to be collected to complete the analysis.

Alternative Development

Alternatives can be developed on the terminal screen over any data theme or combination of data themes that may be useful in developing an alternative.

For example, you may wish to develop an alternative with the following criteria to address an issue or combination of issues: 1) harvest will only take place in Management Area E1, 2) harvest will be restricted to tractor logging, 3) harvest will only take place in stands of high risk lodgepole pine, and 4) areas of critical elk security cover will be avoided by a two sight distance.

To develop this alternative on the terminal with INFORMS to meet the above criteria, we would do the following: 1) call up the management area theme and shade all management areas except E1, 2) call up the digital elevation (contour) theme

and shade all slopes over 40 percent, 3) call up the lodgepole risk theme and shade all areas but high risk lodgepole, and 4) call up the elk cover theme and shade areas of critical elk security including a two sight distance buffer. The remaining unshaded area is ground meeting the criteria for harvest on which this alternative can be developed.

The next step would be to overlay the existing and proposed road systems from the transportation theme. Other themes may be employed, such as soils, etc., if there is a concern or a need for their use in the development of an alternative. Once an alternative is developed on the terminal, you may wish to run it through the visual model if there are concerns on how it will appear from a given location. Modifications are easy to make and run back through the model. Other data, such as volume, acreage, etc., are easy to generate. Using INFORMS, a wide range of alternatives can be developed that are specific to criteria designed to address issues and concerns.

Estimating Effects

Based on the issues and concerns identified in the scoping process, selected resource response or impact models are used for each alternative to display the effects on a particular resource by the alternative being evaluated. The effects of an alternative on a resource are displayed in map or graphic and tabular form.

Evaluating Alternatives

Quantified graphic and tabular display of the effects of an alternative on a resource value that may be an issue or concern makes the job of the Interdisciplinary Team who must recommend an alternative a lot easier. Alternatives can easily be compared for their effect on a particular resource value. This in turn simplifies the job of weighing the benefits and impacts of the alternative being evaluated.

Identification of Preferred Alternatives

INFORMS aids the line officer or resource manager in the selection process by providing data on the effects of each alternative on resource values in map or graphic and tabular form that is displayed in common format.

The data displayed are generated by a common process that is repeatable, and information used to generate the data is of the same quality standards.

The deciding official can play "what if" if not completely satisfied with a recommended alternative and modify or refine an alternative and see what changes in effects on resource values are caused by the modification. Also, if an issue arises that is not addressed by an alternative, it is easy to develop a new alternative that addresses that issue. The data on effects make the process of documenting the rationale for a decision in a Decision Notice much easier.

Monitoring

INFORMS aids the resource manager in monitoring of a project because the process used to estimate effects is repeatable and the intermediate steps are visible and documented. If monitoring shows predicted effects are off from what is actually experienced, then the parameters of the model can be changed to more accurately reflect actual response.

SUMMARY

INFORMS can be used to help resolve complex natural resource problems more easily and efficiently, without requiring resource managers to become tool experts. By integrating models that simulate ecosystem interactions, managers were able to gain a better understanding of the interrelationships of the resources. With the increased speed and repeatability of INFORMS, managers "fine tuned" their decisionmaking. Designed primarily as an integrating shell, INFORMS assumes technology will continue to evolve, and allows for adaptation - an important feature.

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CASE HISTORY: NORTHERN REGION FOREST SERVICE EASTSIDE ZONE--MOUNTAIN PINE BEETLE CONSIDERATIONS

Richard J. Call

ABSTRACT: In the fall of 1985, personnel assigned to the Three Forest Timber Zone recognized the need for a coordinated strategy for responding to the mountain pine beetle threat in the Deerlodge, Lewis & Clark, and Helena National Forests. A task force was implemented which developed six alternatives. The three Forest Supervisors selected an alternative which places emphasis on harvesting green lodgepole pine while retaining the timber sales program at Forest Plan levels. The selected alternative offers maximum flexibility for adjusting programs between Ranger Districts, concentrating on infestation areas and areas of high risk.

During the fall of 1985, it became increasingly apparent that a three-forest strategy was needed for responding to the threat of a mountain pine beetle (MPB) attack in the suspectible stands on the Deerlodge, Helena, and Lewis & Clark National Forests. A zone-wide task force consisting of three District Rangers and three silviculturists from the zone, plus personnel from the Flathead Forest and from the Regional Office, was assigned the duty of assessing the potential of a MPB attack and preparing a report which would provide some alternatives for response. The need for a report and a coordinated strategy was prompted by the following perceptions:

* Hot spotting - each Forest appeared to be responding to the isolated outbreaks in an individual manner. There appeared to be no broad overview being looked at across the Three Forest Zone, and no attempt was being made to develop a consistent zone wide response.

* Organizational changes - several recent arrivals to the zone timber organization were reassigned from forests in the Forest Service Northern Region where MPB epidemics were in process. Experiences on these forests heightened an awareness of the potential for a MPB attack.

* The Draft Forest Plans for each Forest provided good direction to harvest old-growth lodgepole and ponderosa pine ahead of a MPB attack.

* A recent silviculture review on the Lewis & Clark Forest highlighted the potential for a MPB attack.

The objectives of the MPB Task Force were as follows:

* Describe the problem.

* Gather necessary data.

* Develop a range of alternatives.

* Present a report to the three Forest Management Teams.

Data gathering began by identifying mature and overmature lodgepole pine and ponderosa pine types on old, but available, timber type maps (1960's vintage). Specifically, the high-risk and moderate-risk stands were identified on overlay material. The overlays were then compared to the Draft Forest Plan maps which highlighted those stands in the suitable timber base on each Forest. Estimates were then developed of the acreage on each Forest of high risk and moderate risk stands.

A series of overlays were then prepared which showed MPB attacks on each Forest for the period 1976 through 1985. Projections were then made of where the MPB could reasonably be expected to move in the next 10- to 15-year period. These projections were transferred to forest plan maps, which became the basis for further estimates of the volume and value of the timber expected to be killed by the MPB.

Using available subcompartment maps showing P.I. type and forest strata, mortality predictions were developed using the INDIDS model, which predicts 10-year losses for stands within or adjacent to active infestations. Estimates of stumpage values were assigned to the projected losses so that a zone-wide potential loss calculation could be obtained.

Paper presented at the Symposium on the Management of Lodgepole Pine to Minimize Losses to the Mountain Pine Beetle, Kalispell, MT, July 12-14, 1988.

Richard J. Call is Zone Timber Staff Officer, Helena National Forest, Forest Service, U.S. Department of Agriculture, Helena, MT.

The following table shows the potential volume loss of lodgepole pine (LPP) and ponderosa pine (PP) during the next decade for each Forest in the Three Forest Zone.

Potential Loss Calculation

	Allocation To TM (Acres)	High Risk LPP/PP (Acres)	Potential Loss (MMBF)
Deerlodge	352,000	208,000 (LPP)	1,067
L & C	282,000	137,000 (LPP) 6,000 (PP)	719 (LPP) 35 (PP)
Helena	251,000	113,000 (LPP)	791
Total	885,000	458,000 (LPP) 6,000 (PP)	2,577 (LPP) 35 (PP)

Using the available information, the MPB Task Force developed six alternatives for response to the potential MPB attack.

Alternative 1 - Continue existing direction as provided in the three draft forest plans. Approximately 70 percent to 80 percent of regulated harvest would be implemented in the high-risk lodgepole pine and ponderosa pine types.

Alternative 2 - Concentrate zone harvest almost exclusively (95 percent plus) in LPP/PP timber types while being responsive to identified minimum industry requirements for other species and non-sawlog components. Retain district and forest program levels.

Alternative 3 - Concentrate harvest in LPP/PP types. Adjust district level programs as needed to salvage major outbreaks and to develop and harvest large areas of high risk LPP. Retain forest level programs. Emphasize development of high risk stands using the capitol investment program.

Alternative 4 - Concentrate harvest in LPP/PP types. Accelerate harvest of green volume during the early years of the next decade. Reduce harvest accordingly during the later part of the decade so that decade allowable sell quantity is maintained for each forest within the zone.

Alternative 5 - Concentrate harvest in LPP/PP types. Accelerate harvest of green volume on each forest for the entire decade. Exceed ASQ on each forest by approximately 50 percent. Adjust final forest plans to reflect major changes in harvest levels.

Alternative 6 - Concentrate harvest in LPP/PP types. Consider the three forest's ASQ as one timber program rather than individual forest or district programs. Implement the zone program with the objectives of developing and placing under contract large areas of high risk LPP, and salvaging major outbreaks. Do not accelerate harvest.

In September, 1986, the three Forest Supervisors met in Helena to discuss and reach agreement on a coordinated response to the threat of a MPB infestation. The group discussed the MPB Task Force Report and examined the 1986 MPB survey reports which had just been completed for each Forest.

The Forest Supervisors adopted Alternative 3. The primary reasons for selection of Alternative 3 were that it permitted final forest plans to be completed without major overhaul; it kept response to the threat in line with the actual rate of infestation; it could be accomplished with existing funding and personnel; and finally Alternative 3 harvest levels could be accelerated through forest amendments if the need arose in the future.

The Forest Supervisors sent the following seven step process to the District Rangers as direction for implementing Alternative 3:

1. Annually, identify high-risk stands
2. Prioritize high-risk stands
3. Determine road access needs
4. Translate into timber sale proposals
5. Make appropriate adjustments to the 10-year plans
6. Report 10-year plans to Forest Supervisor by March 1, annually
7. Timber zone consolidate into three forest programs

In summary, preparation of the MPB Task Force Report accomplished three major objectives: it pulled a substantial amount of existing data into one report; it raised the level of awareness of Line and Staff Officers within the zone to the threat of a MPB infestation; and, lastly, it has allowed the Three Forest Zone to proceed with harvest and development plans in a coordinated manner.

SILVICULTURAL STRATEGIES TO MINIMIZE MOUNTAIN PINE BEETLE LOSSES--AN OVERVIEW

James H. VanDenburg

ABSTRACT: A mountain pine beetle epidemic started in the Flathead National Forest in 1975. An environmental analysis was completed in 1979. This paper reviews the chosen alternative, silvicultural guidelines, and findings after 9 years.

INTRODUCTION

The mountain pine beetle epidemic in the Flathead National Forest actually started in Glacier National Park in 1972. By 1975 it had expanded to the Glacier View Ranger District adjacent to the Park on the west. From there it spread farther west to the Tally Lake Ranger District. In 1979, the Forest prepared an Environmental Analysis of the MPB situation it found itself in.

E.A. REPORT

The chosen alternative called for a revision of the Flathead Forest 5-year timber sale plan. This encompassed the following:

The Tally Lake District will compress a previously scheduled 6-year program into 3 years, FY 1980-82. The District has inventoried 320 million board feet of high-risk lodgepole pine, of which approximately 160 million board feet is to be programmed for sell during the 3-year period. Other Districts and engineering personnel and resources will be assigned to Tally Lake projects in order to maintain a balanced Forest workload. The District will assure access is planned to all high-risk stands.

The Swan Lake District sell program will also be directed primarily to high-risk lodgepole pine. This District has substantial areas of high-risk lodgepole pine currently under contract, or programmed for sell in the ensuing 5-year program. Additional surveys will be conducted in the 1979 field season to assess the potential for rapid buildup of the mountain pine beetle in the District. Insect and disease funds are available to assist in this work. Special emphasis will be directed toward the Island Unit west of Kalispell, which is closest to the infection source. The District will work closely with Burlington Northern Railroad and the State of Montana where their lands are intermingled with National Forest lands. The District will assure access is planned and developed to all high-risk stands.

The Glacier View District will continue cleanup and salvage of infested lodgepole pine. District lodgepole volumes are expected to drop off substantially after FY 1979. The epidiemic stage will have essentially subsided on available commercial forest land.

The remaining two Flathead Ranger Districts, Hungry Horse and Spotted Bear, will conduct surveys during the 1979 field season to determine the status of infestations in their Districts. Insect and disease funds are available to assist in this work. Preplanning for access and harvest should proceed as the situation warrants.

With the chosen alternative in place, the task fell to the Districts to implement the direction. Silvicultural guidance provided by the E.A. was as follows:

1. Prioritize treatment of lodgepole pine stands to those of most imminent susceptibility to insect attack. Utilize the mountain pine beetle risk inventories and incorporate the factor of stress in predisposing trees previously non-susceptible to epidemic mountain pine beetle populations to successful attack and the resultant high brood production that key epidemics.

2. When feasible and sound, silvicultural regeneration methods other than clearcutting should be used. This guideline is compatible with the NFMA and Forest policy, and will assist development of mixed species stands and reduce certain resource impacts.

3. Attempt to obtain a diversity of timber species, avoiding where possible regeneration to pure lodgepole pine stands. Artificial regeneration may be necessary in some situations to assist this requirement.

4. In compliance with laws and regulations, and to reduce potential for adverse resource impacts, ensure that regeneration cuts are fully restocked within a 5-year period following harvest.

Paper presented at the Symposium on The Management of Lodgepole Pine to Minimize Losses to Mountain Pine Beetle, Kalispell, MT, July 12-14, 1988.

James H. VanDenburg is Forest Silviculturist Flathead National Forest, Forest Service, U.S. Department of Agriculture, Kalispell, MT.

5. Long-term silvicultural prescriptions should recognize the importance of creating lodgepole pine age class diversity by varying rotation lengths within legal constraints and timber management plan guidelines.

6. Silvicultural treatments should be fully responsible to other resource management requirements and constraints itemized in this section.

DISCUSSION

Silvicultural Management Systems that have been employed by the Districts over the last 9 years to combat the MPB epidemic are a variety of harvest treatments aimed at capturing as much green lodgepole as possible within existing constraints of other resources. These treatments included clearcutting, seed tree, shelterwood, sanitation, salvage, and partial cutting. Obviously, as most high-risk stands were predominately pure lodgepole pine, or nearly so, clearcutting became the most frequently used harvest method. Where three to 10 relatively good seed trees were available, usually western larch, the seed tree method was employed. Occasionally, shelterwood, sanitation, or salvage were used where those systems were appropriate. They usually occurred in mixed stands where large lodgepole pine were desirable to harvest and when a manageable stand could be left. Within the last several years, some partial cutting in lodgepole stands to a residual basal area of around 100 square feet was used. These stands were in areas where other cutting methods could not be used effectively due to other resource constraints.

SUMMARY

Looking back at the last 9 years of dealing with the mountain pine beetle in the Flathead Forest, we have realized a number of things that can be shared with others facing similar conditions.

1. Consider lodgepole pine stands for management as soon as possible. The idea of "use it or lose it" applies with mature lodgepole pine more than some other longer lived species.

2. Stand exam information can be invaluable in helping determine priorities for treatment of lodgepole pine, and risk rating models can be run from stand exam data.

3. After risk rating, diagnosis, and prioritizing lodgepole stands, silviculture prescriptions can be prepared.

4. Clearcutting will likely be the harvest method most utilized due to the fact that the highest priority stands for removal are those which contain the largest volume of green lodgepole pine.

5. Many clearcuts will exceed 40 acres either by themselves or when considered with adjacent cutover areas. This is a temporary condition until management objectives are met and areas are no longer considered openings. In timber management areas, this is when the areas are certified as stocked.

6. The Flathead Forest considered the harvest of green lodgepole pine preferable to harvesting dead lodgepole, or leaving dead standing. However, at best, only 80 percent (or less) of lodgepole stands can be harvested in a given area for various reasons.

7. Consideration should be given to those stands which cannot be harvested for various reasons. These stands should also be prioritized by their value to other resources. Remember, dead lodgepole pine does not provide cover for wildlife or pump water for the watershed. However, existing understories may.

8. Consider that dead lodgepole left will eventually fall down, impede wildlife use and movement, and create a fire hazard. All in all, these areas likely will not meet management objectives for some time.

9. Regeneration should be well planned and prompt. In many stands, lodgepole pine will regenerate naturally if cones are left on the ground and there is adequate site preparation. Species diversity should be considered on an area basis, so that future stands will have desirable management opportunities. The area should have species diversity; individual stands may not. Trying to build species diversity into every stand has proven expensive and unnecessary.

10. In the future, stocking control and other intensive management should prevent the mountain pine beetle from impacting the Flathead Forest in the manner that it has in the past.

PARTIAL CUTTING (SANITATION THINNING) TO REDUCE MOUNTAIN PINE BEETLE-CAUSED MORTALITY

Kenneth E. Gibson

ABSTRACT: Data collected over the past decade have shown partial cutting to be a viable management alternative in lodgepole pine stands threatened by mountain pine beetle. Now this strategy is being used operationally as an alternative to clearcutting. Criteria for selecting suitable stands are included.

INTRODUCTION

As has been pointed out repeatedly in this symposium, the mountain pine beetle (MPB) and lodgepole pine (LPP) stands have an extremely long history of interaction. In a purely ecological setting, that interaction would have to be viewed as a mutally beneficial one. Despite the host tree being killed, in its death it sets the stage for a stand-replacing fire--often thought to be necessary because of cone serotiny exhibited by LPP. Now, however, we find ourselves in direct competition with MPB for the resources and amenities found in LPP forests. Suddenly, terms such as "loss," "catastrophy," and "disaster" are associated with the MPB/LPP relationship.

For decades, we have diligently recorded locations of outbreaks, cataloged mortality rates, and planned strategies to combat the MPB menace. Beginning in the 1920's and continuing to as recently as 15 years ago, major Forest Service efforts were directed at killing beetles (Klein 1978). Indeed, some suggest--and I'm not taking issue with the notion--that this is still a viable strategy under certain sets of conditions. Amman and Baker (1972) pointed out as early as 1972 that where efforts to control MPB outbreaks are concentrated on the beetle and susceptible stand conditions remain, infestations will recur in those stands again and again until, ultimately, the effect on the stand will be the same--though prolonged.

Though we are sometimes slow to get the message Mother Nature is trying to tell us, with diligence we usually come through! Such was the case in our efforts to curb mortality attributed to the MPB. By the mid-1970's, we finally came to realize that the only truly successful and long-term method of combating the beetle was to reduce its opportunity to increase to outbreak proportions by removing or changing susceptible stand conditions. Unfortunately, because of an array of political, social, and economic factors--and very few biological ones--it has taken us nearly a decade and a half to develop, demonstrate, and implement strategies useful in forestalling losses to MPB.

MANAGEMENT RECOMMENDATIONS

Speakers at this symposium have described, or will, management strategies for various stand conditions which, if implemented, would help reduce or eliminate beetle-caused mortality. Recommendations vary with age and stand conditions--whether stands are pure LPP, immature, mature, or overmature; or mixed species stands in those same categories. Most successful recommendations propose the creation of age, size, or species mosaics to eliminate large expanses of susceptible host material. The wisdom of those recommendations has been proven over the last decade as we have responded to impacts or threats from MPB.

Most often, the silvicultural recommendation of choice, particularly where LPP is imminently susceptible to beetle depredations, is stand removal. Because of LPP's short-lived nature and the relatively high expense of harvesting smaller diameter logs, clearcutting is frequently the most reasonable alternative. Now, however, in many areas--management units, primary and secondary drainages, compartments and stands--losses, or actions taken to reduce threatened losses, have resulted in the need to consider alternatives to clearcutting.

ALTERNATIVES TO CLEARCUTTING

Beginning about 1976, alternatives to clearcutting were being proposed and tested in LPP stands in the western United States. Cahill (1978) reported on work done in Colorado, Hamel (1978) described early efforts in southwestern Montana, and Cole et al. (1983) detailed partial cutting strategies in Wyoming. Those promising results led to the development of demonstration areas on the Kootenai

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Kenneth E. Gibson is an Entomologist, Timber, Cooperative Forestry and Pest Management, Northern Region, Forest Service, U.S. Department of Agriculture, Missoula, MT.

and Lolo National Forests in Montana in 1978. Results of those demonstrations have recently been reported by McGregor et al. (1987). With their permission, I would like to briefly summarize their findings:

> On each Forest, three levels of diameter limit cutting--all trees over 7 inches d.b.h., all trees over 10 inches d.b.h., and all trees over 12 inches d.b.h.; and three levels of spaced thinnings--residual stocking of 80 sq. ft./acre, 100 sq. ft./acre, and 120 sq. ft./acre--were installed. Unthinned check areas on each Forest were also monitored. Cutting began in 1978 and was completed in 1980. At the time, both areas were experiencing extremely heavy MPB infestations. Evaluations in 1985 showed losses to MPB were greatly reduced in the partial cut areas--regardless of type--when compared with unthinned stands. Numerical results for the Kootenai study areas showed total average mortality were as follows: 6 percent in the 10-inch cuts, 8.6 percent in 12-inch cuts, 7.8 percent in 80 BA cuts, 4.0 percent in 100 BA cuts, 38.6 percent in 120 BA cuts, and 93.8 percent in unthinned checks. Lolo study areas showed the following: 6.9 percent in the 10-inch cuts, 17.1 percent in the 12-inch cuts, 6.7 percent in the 80 BA cuts, 6.0 percent in the 100 BA cuts, 13.1 percent in 120 BA cuts, and 73.1 percent in unthinned checks. All in all, results most impressively document the effects of partial cutting.

Follow-up studies have shown immediate effects are realized by altering stand conditions to ones less favorable to the beetle (Bartos and Amman, in press). Long-term benefits are effected by a growth response in released trees. In summary, viability of partial cutting as an alternative to regeneration harvests has been clearly demonstrated--when the only other option is unacceptable beetle-caused mortality.

OPERATIONAL PARTIAL CUTTING

Beginning in 1982, management plans were developed for LPP stands threatened by MPB on the Swan Lake Ranger District, Flathead National Forest. Beetle populations had begun to increase markedly on the District in 1981. Within the next 2 to 3 years, clearcutting in response to beetle threats had resulted in hydrologic limits being nearly reached in some drainages. In addition, essential big game cover was also being seriously depleted. Despite the best efforts, additional LPP stands were being threatened by ever-increasing beetle infestations.

Basing prescription development on preliminary results of the Lolo and Kootenai demonstration areas, Bollenbacher (pers. comm.) devised sanitation thinning regimes for three stands in the District. These were stands almost certain of being infested, but ones for which clearcutting was not desirable.

Prior to thinning, stands ranged from 164 to 183 square feet of basal area. They were thinned to 92, 112, and 143 square feet--two in July 1985, the other in September 1986. Because larger, more vigorous trees were left, average stand diameter increased from 7-8 inches, to 8-9.5 inches. Following beetle flight in 1986, adjacent uncut areas had experienced beetle attacks ranging from 20 to 53 percent of the stand. In the three thinned stands, beetle-caused mortality was zero, 5 percent and 16 percent. The latter was immediately adjacent to the most heavily infested uncut stand and may have been under attack at the time it was being cut. Evaluations made after beetle flight in 1987 showed infestations continuing in all adjacent areas while no new attacks were observed in any of the thinned stands (Gibson 1988).

Following his experiences with sanitation thinning, Bollenbacher has developed guidelines which can assist the land manager in evaluating the practicality of that strategy for a particular set of conditions. They are:

1. Site productivity: Better sites will add to the likelihood of increased growth and vigor of leave trees.

2. Slope: As a rule, treat stands on tractor ground of less than 35 percent to limit residual stand damage.

3. Average stand diameter: Choose stands where average d.b.h. exceeds 9 inches with less than 350 trees over 5 inches d.b.h. per acre. Such stands will be more economical to log with less residual damage.

4. Age: Stands should be between 60 and 125 years old.

5. Current stocking: Stands should have at least 130 sq. ft./acre basal area to make an economical logging opportunity.

6. Elevation: Consider stands where longer growing seasons translate to higher MPB risk. For northwestern Montana, that is 6,000 feet elevation or less.

7. Wind firmness: Choose most sheltered slope position. Refer to Alexander's (1975) risk categories.

8. Present MPB status: Stands should have present infestation rate of 10 percent or less.

9. Tree vigor: Candidate stands should have crop trees with live crown ratio of 30 percent or greater.

10. Other resource objectives: Consider only those stands where other resource objectives may not be met through regeneration harvesting (Bollenbacher and Gibson 1986).

CONCLUSIONS

In summary, research, demonstrations, and operational programs have shown partial cutting to be a sound silvicultural alternative in LPP stands threatened by MPB. As noted, that is not to suggest that partial cutting is the preferred alternative in every situation; rather, it can be used to great advantage when all resource considerations dictate clearcutting is not appropriate. Given the changes wrought by MPB in LPP stands in the past decade, and the susceptible stands remaining, that may occur more and more often before current infestations have run their course.

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WHY PARTIAL CUTTING IN LODGEPOLE PINE STANDS REDUCES LOSSES TO MOUNTAIN PINE BEETLE

Gene D. Amman

ABSTRACT: Thinning stands of lodgepole pine (Pinus contorta Douglas var. latifolia Engelmann) greatly minimized tree losses to mountain pine beetles (Dendroctonus ponderosae Hopkins). Although losses were reduced immediately following thinning, trees did not respond with increased growth until the second year after thinning. Tree losses in partial cut stands were more closely related to large tree diameter than to tree vigor indices.

Beetles were trapped in thinned stands for several years after thinnings were completed but were infesting only a few of the residual trees. The altered microclimate of the stands is suspected of being the factor most likely affecting beetle behavior.

Thinning lodgepole pine stands increased light intensity, wind movement, insolation, and temperature. Temperatures on the south exposure of tree trunks and of soil were significantly higher in thinned than unthinned stands.

INTRODUCTION

Silvicultural methods to reduce losses from bark beetles traditionally are aimed at decreasing tree competition and increasing tree vigor (Graham and Knight 1965; Keen 1958), thus making the trees better able to repel attacking beetles with copious resin flow (Reid and others 1967). To test partial cutting of mature lodgepole pine (Pinus contorta Douglas var. latifolia Engelmann) stands to reduce tree losses to mountain pine beetles (Dendroctonus ponderosae Hopkins [Coleoptera: Scolytidae]) (MPB), large-diameter trees were removed from stands on Bureau of Land Management lands near Granby, CO, in 1972 (Cahill 1978). Large-diameter trees favor high beetle production because they have thicker phloem (food of developing larvae) than that found in small-diameter trees (Amman 1972). This treatment resulted in losses to MPB of 1 to 2 percent, whereas tree losses in unthinned stands were 39 percent. Diameter limit cuts on the Gallatin National Forest near West Yellowstone, MT, showed similar reductions in tree losses to MPB (Hamel 1978). Partial cutting tests on the Shoshone National Forest in northwest Wyoming, consisting of (1) diameter limit thinnings that removed all trees 7, 10, or 12 inches and larger d.b.h., (2) spaced thinnings leaving the 50 best trees per acre, and (3) untreated check stands, resulted in losses of less than 1 percent of trees in partial cut stands, compared to 4 percent in check stands the first year following cutting (Cole and others 1983). Five years after the partial cuts were made on the Shoshone National Forest, tree losses to MPB ranged between 0.3 to 7 percent in partial cut stands, compared to 27 percent in unthinned check stands (fig. 1) (Amman and others 1988a). Partial cutting tests on the Kootenai and Lolo National Forests in northwest Montana included (1) diameter limit thinnings that removed either all trees 10 or 12 inches and larger d.b.h., (2) spaced thinnings that left residual basal areas of 80, 100, or 120 ft^2 BA/a, and (3) check stands. Five years after these partial

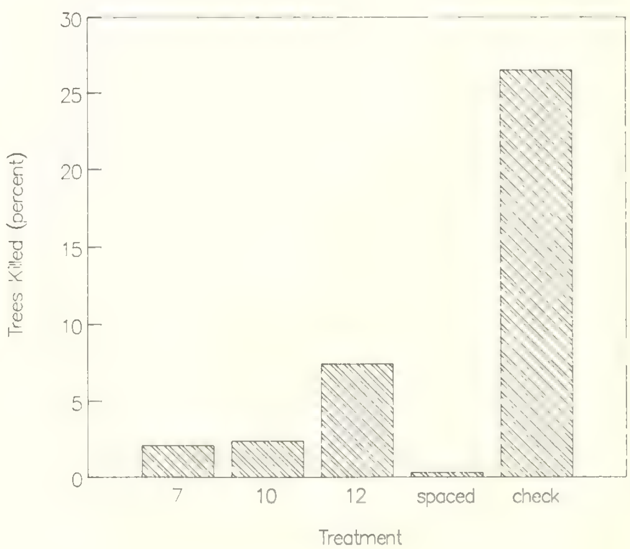

Figure 1--Percent lodgepole pine killed by mountain pine beetles in different partial cutting treatments, Shoshone National Forest, WY, 1981 to 1985 (from Amman and others 1988a). Treatments indicate diameter limit cuts in which all trees 7, 10 or 12 inches and larger d.b.h. were removed; spaced thinnings in which the 50 best trees per acre remained; and untreated check.

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Gene D. Amman is Principal Entomologist, Mountain Pine Beetle Population Dynamics Research Work Unit, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Ogden, UT.

cuts were made, tree losses were less than 17 percent in all partial cut stands except those that left 120 ft² BA/a, where losses were 38 percent. Losses were 73 and 94 percent, respectively, in the Kootenai and Lolo check stands (fig. 2) (McGregor and others 1987). Lodgepole pine losses to MPB also were much reduced in thinnings established 7 to 15 years prior to evaluation of tree losses to MPB in Oregon (Mitchell and others 1983b). Tree losses in the Oregon thinnings averaged 9 percent, compared to 19 percent in unthinned check stands.

Following partial cutting of lodgepole pine stands on the Kootenai, Lolo, and Shoshone National Forests, observations were made of: (1) response of MPB determined by trapping the beetles, and (2) changes in radial growth and vigor indices of residual trees in relation to susceptibility of MPB infestation. A third item, differences in microclimate of thinned and unthinned stands as they relate to MPB infestation, was determined on the Wasatch National Forest in northeastern Utah.

BEETLE RESPONSE TO PARTIAL CUT STANDS

Little is known about the influence of stand environment on the flight and host selection behavior of MPB. What is known has been documented during outbreaks in uncut stands. The fact that the beetle kills the largest diameter lodgepole pines remaining in infested stands during successive years of an outbreak is well documented (Cole and Amman 1969; Hopping and Beall 1948). This observation agrees with laboratory measures of host selection behavior that show the beetle is attracted to large, dark silhouettes (Shepherd 1966) and vertical cylinders (Gray and others 1972; Schönherr 1976). The beetle's apparent preference for large-diameter trees is such that it will infest these trees even when intermingled smaller trees are baited with components of the beetle's aggregative pheromone (Rasmussen 1974).

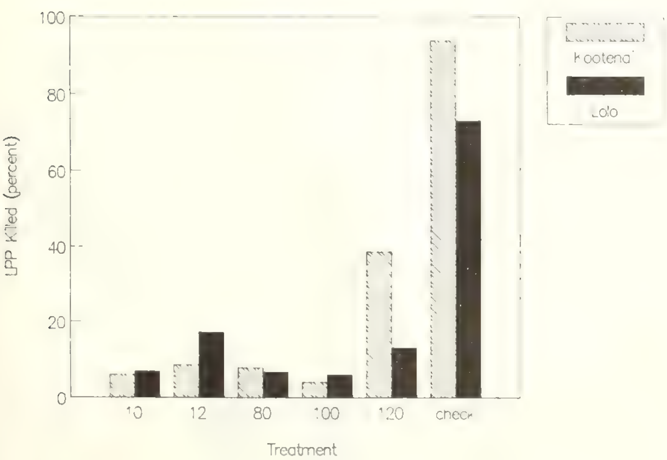

Figure 2--Percent lodgepole pine (LPP) killed by mountain pine beetles in different partial cutting treatments, Kootenai and Lolo National Forests, MT, 1980 to 1984 (from McGregor and others 1987). Treatments indicate diameter limit cuts in which all trees 10 or 12 inches and larger d.b.h. were removed, spaced thinnings leaving 80, 100, or 120 ft² BA/a, and untreated check.

To study how stand density affects the dispersion of MPB in partial cut stands of lodgepole pine, omnidirectional passive barrier traps were used to monitor numbers of MPB in flight (Schmitz and others 1980; Schmitz and others, in press). Traps consisted of two clear Plexiglas panels with funnels and containers at the base of the panels to entrap the beetles that flew into the panels. Each trap had a total intercepting surface above the funnels of 7.75 ft² (Schmitz 1984). Three of these traps were hung on a single nylon cord supported on a horizontal line between the crowns of two adjacent trees. Traps on the line were positioned so they corresponded to midcrown, midbole, and about 6 ft above ground (fig. 3). Two such lines were hung in each stand monitored for beetle flight.

In earlier work on the Gallatin National Forest near West Yellowstone, MT, Schmitz and others (1980) found that most MPB flew in the midbole area. Beetles were caught with about equal frequency in thinned and unthinned stands, but more trees were infested in unthinned stands (Hamel 1978). Numbers of beetles caught among treatments after 4 years on the Kootenai and Lolo National Forests were significantly different

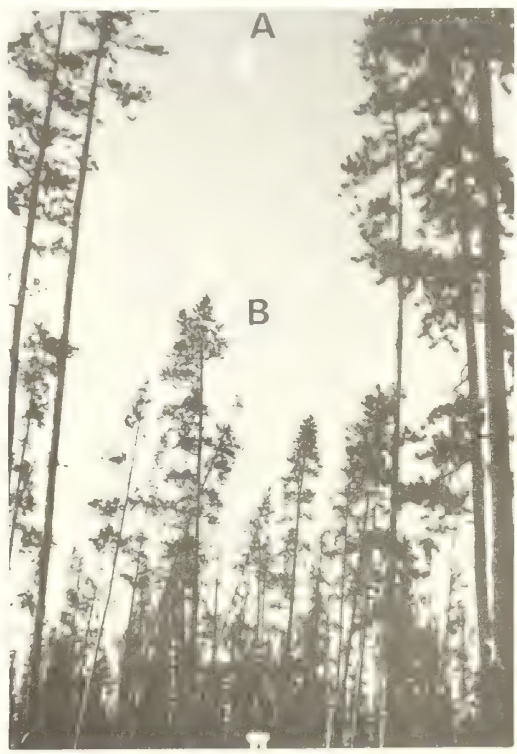

Figure 3--Omnidirectional passive barrier traps used to catch flying beetles: (A) horizontal support line with pulley for attachment of vertical line; (B) vertical line used to raise and lower traps, with three traps attached.

among partial cutting treatments (fig. 4). The treatments separated into two groups. Group one had the fewest beetles and included stands having 100 ft^2 BA/a of residual basal area and the 10-inch diameter limit cut. Group two consisted of the 120 ft^2 BA/a and the check stands, which had the greatest tree densities. The other two treatments, consisting of 80 ft^2 BA/a and the 12-inch diameter limit cut, did not differ significantly from group one or group two. In general, the greatest numbers of beetles were trapped in group two stands, and the greatest numbers of trees were killed in these stands (Schmitz and others, in press). Comparison of percentages of residual trees killed with MPB trapped between thinned and unthinned stands revealed the percentage of trees killed in the thinned treatments was proportionately less than might have been expected, based on the number of MPB trapped. Overall, the ratio of estimated MPB in flight per tree killed was greater in thinned stands than in unthinned check stands (fig. 5). As on the Gallatin National Forest (Schmitz and others 1980), most MPB were caught in midbole traps (fig. 6) (Schmitz and others, in press). The loss of fewer trees in thinned stands than in unthinned stands proportional to the numbers of flying beetles suggests that many beetles were not stopping to infest trees in thinned stands.

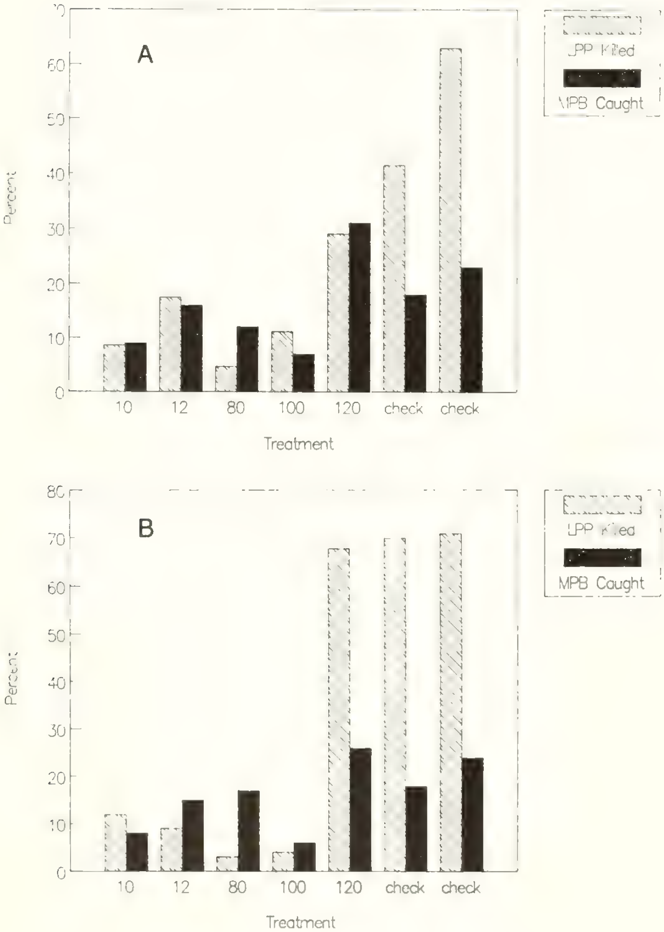

Figure 4--Percentage of total mountain pine beetles (MPB) caught per treatment compared with percentage of residual lodgepole pine (LPP) killed per treatment following thinning in the (A) Lolo and (B) Kootenai National Forests, MT, 1980 to 1983 (from Schmitz and others, in press). Treatments indicate diameter limit cuts in which all trees 10 or 12 inches and larger d.b.h. were removed, spaced thinnings leaving 80, 100, or 120 ft^2 BA/a, and untreated check.

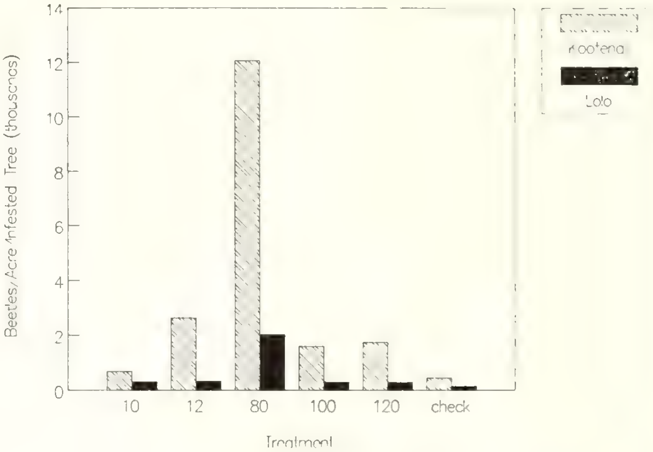

Figure 5--Ratio of estimated inflight beetles (MPB) per acre for each tree killed by mountain pine beetles in partial cutting treatments on the Kootenai and Lolo National Forests, MT (from Schmitz and others, in press). Treatments indicate diameter limit cuts in which all trees 10 or 12 inches and larger d.b.h. were removed, spaced thinnings leaving 80, 100, or 120 ft^2 BA/a, and untreated check.

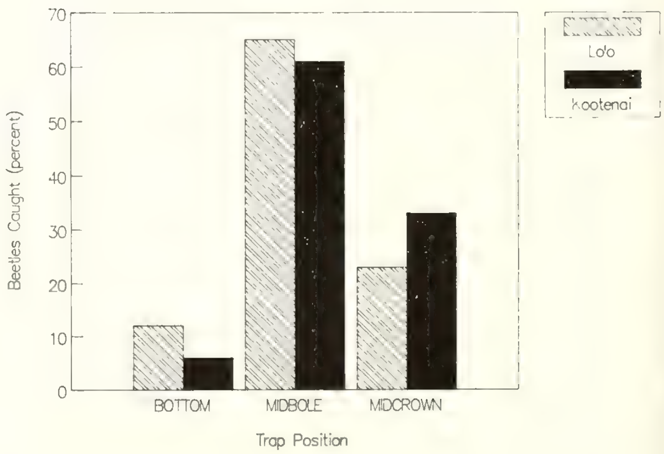

Figure 6--Percentage of mountain pine beetles (MPB) caught by trap position in the Lolo and Kootenai National Forests, MT, 1980 to 1983 (from Schmitz and others, in press).

GROWTH RESPONSE FOLLOWING PARTIAL CUTTING

Radial growth of residual trees in the Kootenai stands was slightly reduced or about the same in 1980 as in 1979, the year of most thinnings. Only trees in the 80 and 100 ft^2 BA/a treatments increased in growth the first year following thinning. Most stands showed increasing growth trends starting in 1981 (fig. 7) (Amman and others 1988b).

The trend in radial growth in the Lolo stands, including untreated checks, also declined the first year following thinning, except for the 100 ft^2 BA/a treatment, which increased slightly (fig. 8). Radial growth for most stands, including check stands, although not quite as large as in the Kootenai stands, showed an upward trend from 1981 through 1984, with the exception of a sharp decline in 1982.

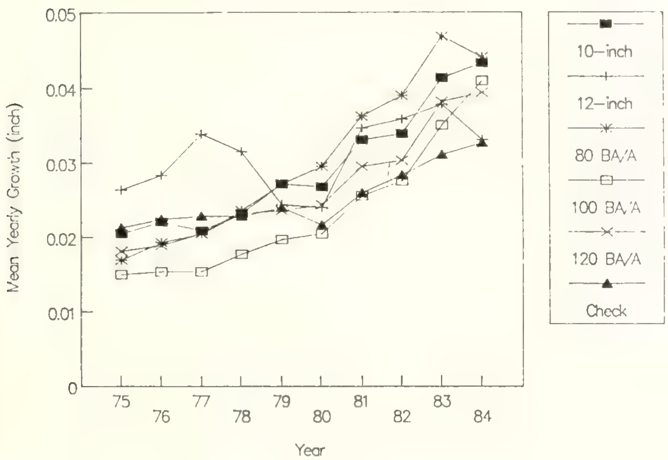

Figure 7--Mean annual growth (radial) of lodgepole pine in partial cutting treatments applied in 1979 to reduce tree losses to mountain pine beetle, Kootenai National Forest, MT (from Amman and others 1988b).

In the Shoshone National Forest, significant radial growth occurred following thinning in 1979 and 1980 (fig. 9). None of the treatments showed decline in growth following thinning, although a slight flattening of the growth curve occurred for the 7-inch and 10-inch diameter limit cuts between 1979 and 1980. Check stands showed a decline in growth during this period. Trees in all treatments, including the checks, had substantial live crown, with averages ranging between 46 and 63 percent of total tree height. However, only the check stands did not respond with a significant increase in radial growth, but the trend in growth was up. Apparently, reductions in numbers of trees caused by MPB were not large enough to provide as rapid growth response as partial cutting treatments on the Kootenai and Lolo National Forests. Extensive tree mortality in check stands on the Kootenai and Lolo resulted in significant growth response of residual trees.

Five years after partial cuts were made on the Kootenai and Lolo National Forests, none of the stands were considered vigorous. Lodgepole pines, with average ages of 102 and 76 years on the Kootenai and Lolo, respectively, and 100 on the Shoshone, are past the age when maximum resin response to MPB infestation could be expected (Shrimpton 1973). Trees were growing at a slow rate prior to and for several years after thinnings were completed. Although average radial growth of trees in some stands increased 100 percent by the fourth year following thinning, this was only an increase of 0.02 inch.

The first year following thinning, most stands showed a slight reduction in growth. Because thinning tends to improve moisture availability in thinned stands, Donner and Running (1986) suggested that a negative growth response following thinning is probably caused by reduced

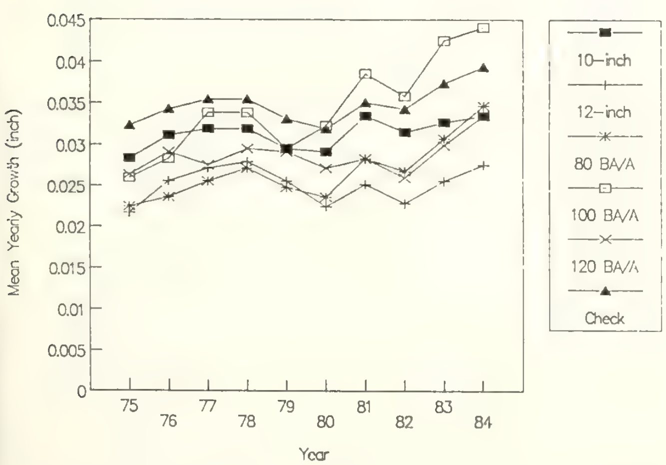

Figure 8--Mean annual growth (radial) of lodgepole pine in partial cutting treatments applied in 1979 to reduce tree losses to mountain pine beetle, Lolo National Forest, MT (from Amman and others 1988b).

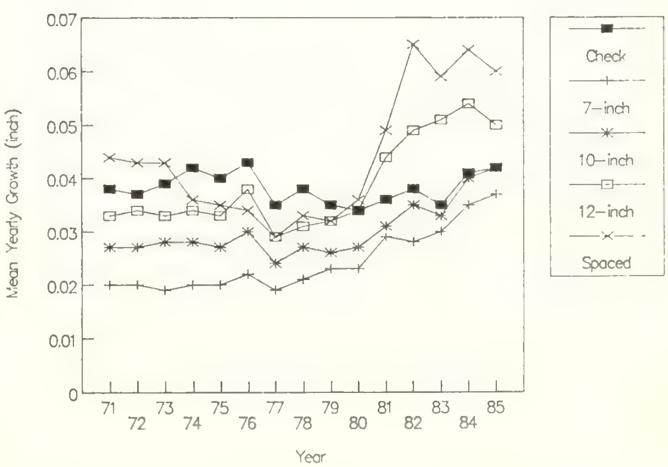

Figure 9--Mean annual growth (radial) of lodgepole pine in partial cutting treatments applied in 1979 and 1980, Shoshone National Forest, WY (from Amman and others 1988a).

photosynthetic capacity related to loss of shade leaves after exposure to full sunlight. During this first year (1980), growth probably was limited to root and shoot growth because radial trunk growth is the last to occur (Waring 1983). An increase in radial growth started the second year following thinning in all stands, including checks, on the Kootenai, Lolo, and Shoshone, probably because of increased moisture following thinning. Increased diameter growth following thinning can be expected in nearly all ages and densities of lodgepole stands that have not lost their physiological capability to recover from stagnation (Cole 1975). Reduced tree losses to MPB following partial cutting should not have occurred on the basis of tree growth because growth was so small.

TREE VIGOR FOLLOWING PARTIAL CUTTING

Several tree and stand characteristics have been related to susceptibility of MPB infestation (Amman and others 1977; Berryman 1978; Cole and McGregor 1983; Mahoney 1978; Safranyik and others 1974; Schenk and others 1980; Shrimpton 1973; Stuart 1984; Waring and Pitman 1980). Many of the variables measured for these methods are more appropriate for natural stands than for recent partial cut stands. For example, variables related to tree competition as a precursor to MPB infestation would be inappropriate, since thinning reduces numbers of trees below the level of intertree competition. These variables include crown competition factor (CCF) (Schenk and others 1980; Berryman 1978) and stand density index (SDI) (Anhold and Jenkins 1987). The resinous response of trees to inoculation of blue-staining fungi (Ceratocystis clavigera [Robinson-Jeffrey and Davidson] Upadhyay) (Raffa and Berryman 1982; Shrimpton 1973) also is inappropriate, since blue-stain inoculations did not distinguish lodgepole pine that were susceptible to MPB infestation in natural stands (Peterman 1977). Three tree characteristics that can be applied to thinned as well as natural stands are diameter at breast height (d.b.h.) (Amman and others 1977; Cole and McGregor 1983; Safranyik and others 1974; Stuart 1984), periodic growth ratio (PGR), which is the current 5 years of radial growth divided by the previous 5 years of radial growth (Mahoney 1978), and grams of wood produced per square meter of foliage (Mitchell and others 1983b). These three risk-rating methods were applied to trees in partial cuts on the Kootenai, Lolo, and Shoshone National Forests. Comparisons were made between the characteristics of trees killed by MPB and adjacent live trees, using analysis of variance (ANOVA) and discriminant analysis.

Discriminant analysis is a procedure that uses measurements on a series of characteristics to classify individuals into categories. Once a function has been developed to perform this, it can be used to classify individuals of unknown origin into the category to which they most likely belong. Diameter at breast height was found to be the most discriminating of the variables measured (table 1). PGR and grams of wood per square meter of foliage were larger in trees killed by MPB in half of the partial cuts, and larger in surviving trees in the other half of the partial cuts. Therefore, these characteristics were not useful in discriminating between susceptible and nonsusceptible trees in the partial cut stands (Amman and others 1988b). The discriminant function showed that 69.4 percent of live trees had characteristics of live trees, whereas 30.6 percent of live trees had characteristics of dead trees. In contrast, 75 percent of dead trees had characteristics of dead trees and 25 percent had characteristics more closely related to live trees (table 2). A large, squared distance between the means of the standardized value for the discriminant function indicates it is easy to discriminate between the groups. The squared distance is a function of the group means and the pooled variances and covariances of the variables (Afifi and Clark 1984). The pairwise squared distances, based on d.b.h., grams of wood, PGR, and leaf area, between live and MPB-killed

Table 1--Probability of >F for discriminant analysis

	One-way ANOVA				Multivariate
Treatment	DBH	Grams of wood	PGR	Leaf area	Wilk's Lambda
10-inch diam. limit	0.7092	0.7092	0.7092	0.7092	0.7092
12-inch diam. limit	0.0560	0.7013	0.7895	0.5273	0.1420
80 ft^2 BA/a	0.0001	0.0693	0.7320	0.0229	0.0001
100 ft^2 BA/a	0.0001	0.5823	0.0151	0.0292	0.0001
120 ft^2 BA/a	0.0001	0.7197	0.4789	0.0001	0.0001
Check	0.0787	0.4671	0.0303	0.2676	0.0448

Table 2--Classification of live and MPB-killed lodgepole pine by the discriminant function

Treatment	Tree condition	Live	Dead	Dead tree characteristics
		- - Percent - -		
10-inch diam. limit	Live	64.0	36.0	
	Dead	0.0	100.0	>DBH <GMS >PGR >LA
12-inch diam. limit	Live	71.4	28.6	
	Dead	39.2	60.8	>DBH >GMS >PGR >LA
80 ft^2 BA/a	Live	67.5	32.5	
	Dead	27.8	72.2	>DBH <GMS <PGR >LA
100 ft^2 BA/a	Live	74.3	25.7	
	Dead	13.8	86.2	>DBH >GMS <PGR >LA
120 ft^2 BA/a	Live	73.1	26.9	
	Dead	23.9	76.1	>DBH >GMS <PGR >LA
Check	Live	66.2	33.8	
	Dead	45.2	54.8	>DBH <GMS >PGR >LA
Average	Live	69.4	30.6	
	Dead	25.0	75.0	>DBH -- -- >LA

trees (table 3) showed greatest distances occurred in the spaced thinnings (80, 100, and 120 ft^2 BA/a) and least distance in the check stands. Distances in the diameter limit thinnings were intermediate, with the 12-inch diameter limit thinning having a value close to the check.

On the Shoshone National Forest, not enough trees were killed by MPB for comparisons to be made between characteristics of killed and surviving trees. However, observations on surviving trees show grams of wood produced per square meter of foliage was still well below the 100-g level dividing susceptible from nonsusceptible trees 5 years after partial cuts were made (Amman and others 1988a). PGR's for all partial cuts exceeded the average for resistant trees, being

Table 3--Pairwise squared distance of the discriminant function for live and mountain pine beetle killed trees

Treatment	Distance
10-inch diam. limit	0.6155
12-inch diam. limit	0.3513
80 ft^2 BA/a	1.7043
100 ft^2 BA/a	2.1662
120 ft^2 BA/a	1.3393
Check	0.3177

1.0 or greater at the start of the test and steadily increasing following partial cutting, even in the check stands, which had losses exceeding 30 percent of the trees.

Following partial cutting, stands should still have been susceptible to MPB infestation, based on vigor indices. Average d.b.h. of most stands exceeded the 8 inches specified by Amman and others (1977) and Safranyik and others (1974); grams of wood per square meter of foliage for most trees were still in the highly susceptible category of less than 50 g; and PGR was less than 0.9 in many trees on the Kootenai and Lolo but not on the Shoshone National Forest. However, tree losses were much reduced. Even though trees had not yet responded with greatly increased vigor, the much reduced losses following partial cutting, when compared to uncut check stands, suggest that some factor other than tree vigor is involved. Bartos and Amman (1989) suggest that stand microclimate is responsible, being altered by the partial cutting treatments.

While grams of wood per square meter of foliage was not a good measure of tree susceptibility to MPB infestation in Montana and Wyoming, Mitchell and others (1983b) found this to be a good predictor of lodgepole susceptibility to MPB infestation in stands on the Deschutes National Forest in Oregon. The stands had been thinned 7 to 15 years before the infestation. In that length of time, most stands had exceeded the 100 g of wood per square meter of foliage that separates susceptible from nonsusceptible stands.

Although stand microclimate was considered as a possible cause for differences in beetle behavior among the Oregon stands, it was not studied (Mitchell and others 1983b).

Quantitative and qualitative changes in resins following partial cutting were not explored in the Kootenai, Lolo, and Shoshone stands, as was done in thinned loblolly pine stands in the southern United States in relation to bark beetle attack (Matson and others 1987; Nebeker and Hodges 1983). Nebeker and Hodges (1983) found total monoterpene content did not change with time or treatment. However, greatest terpene increase occurred in trees receiving basal wounds during the thinning operation. This they attributed to stimulation caused by the wounding. Matson and others (1987) observed greater resin production in residual trees in thinnings than in unthinned stands 6 years after treatment. Because of small changes in growth of lodgepole pine in our partial cutting treatments immediately and even 5 years after partial cutting treatment, substantial increase in resin production seems unlikely. This observation, coupled with the slow radial growth and slow change in tree vigor of residual trees, suggests that factors other than tree vigor are governing whether beetles remain in the partial cut stands to infest trees. The most likely factor is change in microclimate as a result of the partial cuts.

MICROCLIMATE OF STANDS AND TREES IN PARTIAL CUT STANDS

Partial cutting lodgepole pine stands causes subtle changes not only in incident radiation, temperature, and light (Reifsnyder and Lull 1965), but also in wind speed. These climatic changes brought about by thinning may have profound effects on MPB activity. The effects of extremely high (Patterson 1930) and low temperatures (Somme 1964; Yuill 1941) on MPB have been reported. However, an optimum zone for temperature and other microclimatic factors has not been defined. Microclimate was measured and compared for thinned and unthinned stands located at 9,400 ft (latitude 41 °N) on the Wasatch National Forest in northeastern Utah (Bartos and Amman 1989).

Microclimatic factors measured in thinned and unthinned stands in northern Utah were: temperature of the outer and inner bark of live trees, air temperature, soil temperature, solar radiation, and wind speed, using either an automatic recording device and thermocouples or an infrared thermometer. The inner bark (phloem) temperature was consistently 2 to 4 °F higher in the thinned than in the unthinned stand. The outer bark (surface) temperature on the south side was 2 to 5.5 °F higher in the thinned than in the unthinned stand (fig. 10). Less difference was observed on the north sides between thinned and unthinned stands. However, temperatures were 5.5 to 7 °F higher on the south than north sides. These differences are consistent with those reported by Powell (1967) in British Columbia. In addition, he found temperatures of infested trees are higher than those of live trees. Powell (1967) reported subcortical temperatures were occasionally 95 °F or higher on south sides. Bartos and Amman (1989) reported an average difference of 4 °F between north and south sides during the hours of 10 a.m. to 2 p.m., with maximum temperature being 22 °F higher in the thinned than unthinned stand. Temperatures on north sides of trees in thinnings would not deter beetle attack. Cooler temperatures on north sides apparently offer more favorable physical environment for attacking MPB. MPB attack

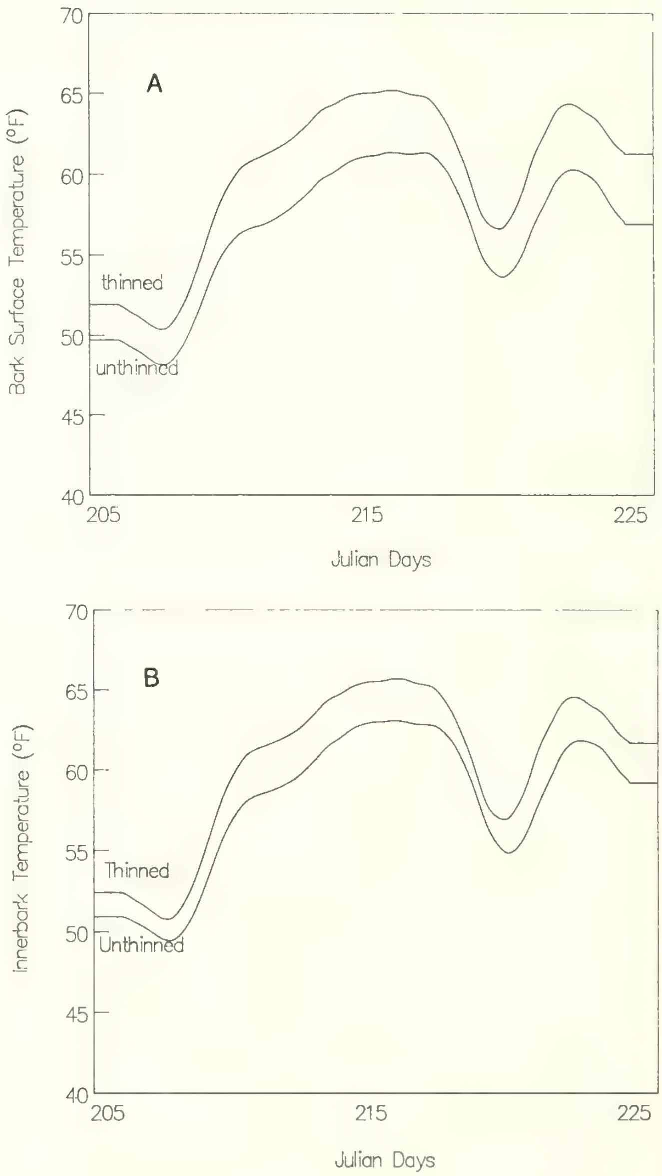

Figure 10--Smoothed curves for a 17-day time period in 1986 contrasting (A) bark surface temperatures and (B) innerbark temperatures on the south side of two lodgepole pine trees between a thinned and unthinned stand (from Bartos and Amman 1989).

densities are higher on north sides (Reid 1963; Shepherd 1965), and when trees are strip attacked, the attacks usually occur on north and east sides (Mitchell and others 1983a).

The effect of temperature could be more subtle than simply creating a direct inhospitable environment for MPB attack. MPB may have evolved behavior to avoid situations where beetle brood are not likely to survive. In thinned stands, high temperatures are not likely to be lethal to any MPB stage (Safranyik 1985). However, where tree temperatures are a few degrees above those of trees in unthinned stands, MPB may proceed too far in their development before winter, thus entering winter in stages that are very susceptible to freezing--for example, the pupal stage--as observed by Reid (1963) and Amman (1973).

The increased wind speed and air turbulence in thinned compared to unthinned stands could disrupt the pheromone communication system of MPB. More sunlight penetrated the canopy in the thinned than unthinned stands (fig. 11), resulting in significantly higher soil temperatures.

Increased soil temperatures, averaging 9 °F higher in the thinned than in the unthinned stand (Bartos and Amman 1989), increase convection currents (Rosenberg and others 1983) and air turbulence that could disrupt pheromone plumes and resultant MPB communication (fig. 12). In addition, wind speed is greater in thinned than unthinned stands (fig. 13), thus possibly further complicating pheromone communications. MPB response to pheromones is more predictable at wind speeds under 3 mph, but a few beetles fly at wind speeds of 4.5 mph. Twice as many males as females fly at wind speeds in excess of 2.4 mph (Gray and others 1972).

In dense stands, sunlight is absorbed by the upper levels of the tree canopy that in turn heat the surrounding air, creating instability in the air within the upper canopy. This creates an inversion in the stem zone that is characterized by more stable air (Chapman 1967; Fares and others 1980). Inversions tend to be more pronounced in dense stands than in sparse ones (Fares and others 1980; Fritschen 1984). Aerosol movement below a dense canopy on a sunny day is trapped beneath the canopy until it flows to a point where the canopy is sparse or has an opening (Fares and others 1980). Solar energy penetrating through canopy openings to the forest floor heats the ground and adjacent air, which becomes buoyant and rises through the canopy opening, carrying the aerosol with it (Fares and others 1980). The aerosol or pheromone plume will be torn apart in the faster, more turbulent air currents that occur above the canopy. Therefore, when MPB infest a tree in a thinned stand, canopy density usually is insufficient to trap the pheromone and move it intact horizontally to attract other beetles. Rather, the pheromone rises through the canopy on convection currents and is dispersed above the canopy. Schmitz and others (in press) concluded that most MPB fly in the bole area beneath the canopy, where the pheromone communication system would be most effective.

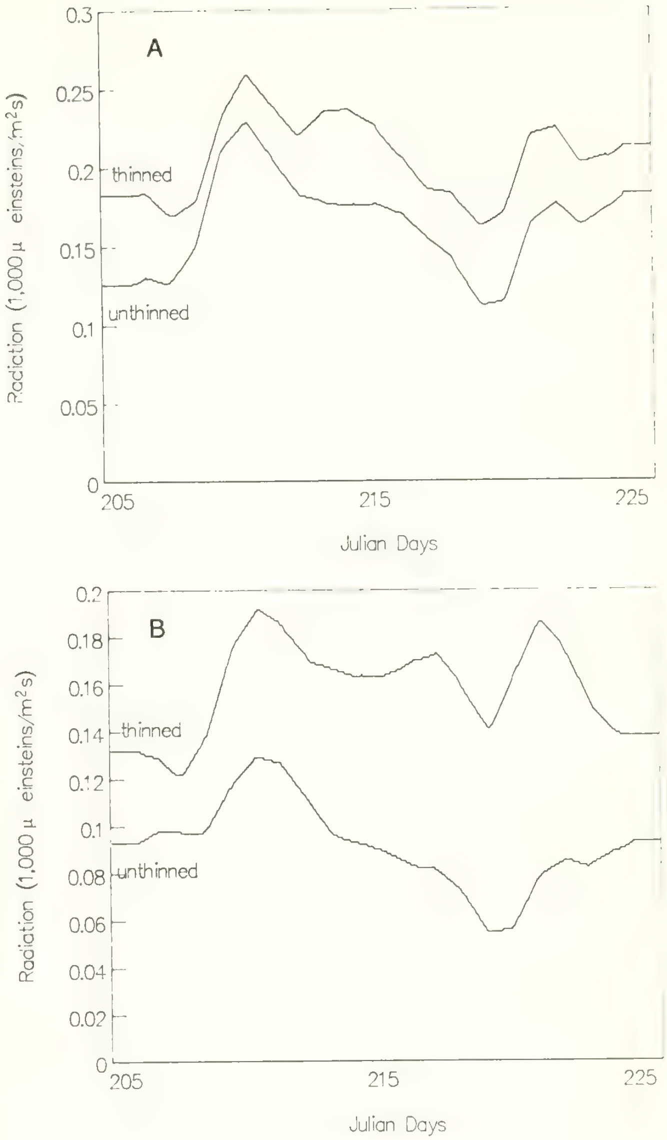

Figure 11--Smoothed curves for a 17-day time period in 1986 contrasting solar radiation (A) at instrument towers and (B) at d.b.h. on trees between thinned and unthinned lodgepole pine stands (from Bartos and Amman 1989).

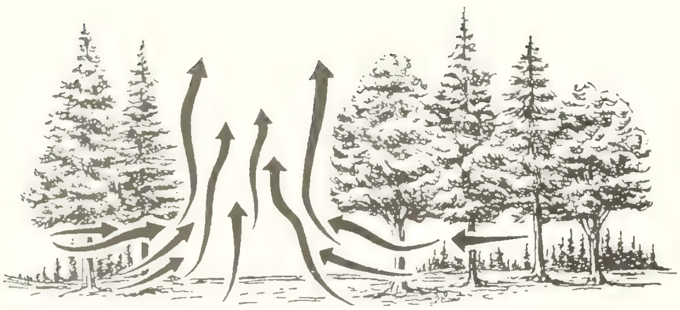

Figure 12--Openings in the canopy tend to act as chimneys when the soil and tree trunks are heated by solar radiation and light winds occur (from Schroeder and Buck 1970).

When MPB do infest a tree in a thinned stand of lodgepole pine, usually only the single tree--and occasionally a nearby tree, when spacing is not maintained--is infested. Geiszler and Gara (1978) emphasized the importance of tree spacing in switching of attacks from a tree under attack to a nearby tree. Trees spaced too far from a tree under attack will not be attacked. The openness of the stand probably causes convection currents created by solar insolation to transport the pheromone plume around infested trees vertically out of the stand rather than horizontally. Thus, the infestation of adjacent trees would be dependent on the degree of thinning. The reduced loss of trees to MPB in all partial cutting treatments in the Kootenai and Lolo studies (McGregor and others 1987) suggests that the density and spacing of natural stands do not have to be changed very much to have an effect on MPB response.

Bartos and Amman (1989) placed three pheromone-baited funnel traps 165 ft apart in both a thinned (67 ft^2 BA/a) and an unthinned stand (137 ft^2 BA/a) that had no currently infested trees. Traps between the two stands were located 330 ft apart. Of the 504 beetles caught, only 5.2 percent were caught in the thinned stands. Either beetles could not find the traps in thinned stands because of disruption of the pheromone plume, or beetles failed to respond because of microclimatic conditions of the stand. Shepherd (1966) showed in laboratory studies that MPB increased attempts to fly as light intensity and temperature increased. Thus, conditions encountered in thinned stands would have been conducive to beetle flight rather than arrestment.

These observations of growth and vigor response of lodgepole pine following partial cutting, MPB response to the partial cut stands, and microclimate changes as a result of partial cutting suggest that microclimate plays a major role in MPB behavior following partial cutting.

Infestation risk of managed lodgepole pine stands probably can be assessed by monitoring stand microclimate, specifically light, which may serve as an integrator of other important microclimatic factors. As tree diameter increases and crown closure begins to occur in partial cut or thinned stands, a favorable microclimate may occur and invite beetle attack, regardless of tree vigor. In addition, thinned stands that contain trees on which branches have not pruned well or that have tall shrub layers may be as subject to beetle infestation as unthinned stands. Additional studies are needed of MPB infestation in thinned and partial cut stands to determine microclimatic thresholds of MPB infestation and the association of thresholds with tree vigor levels, crown lengths, branch pruning, and understory tree and shrub layers.

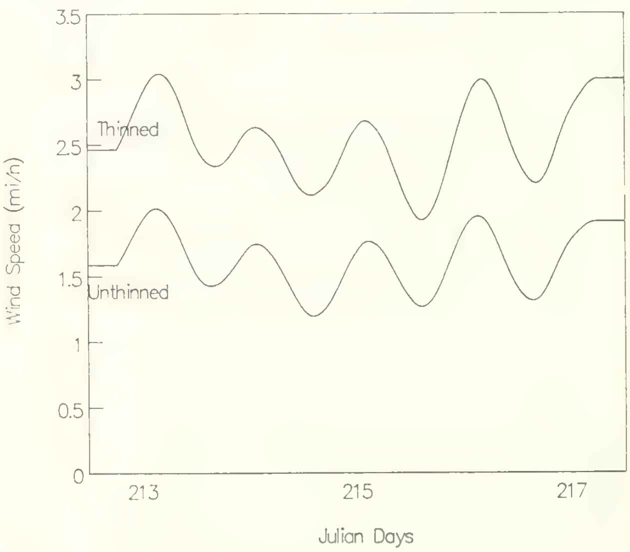

Figure 13--Smoothed curves for a 5-day time period in 1986 contrasting wind speed on instrument towers between a thinned and unthinned lodgepole pine stand (from Bartos and Amman 1989).

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MIXED HOST STRATEGIES FOR MOUNTAIN PINE BEETLE CONTROL IN OREGON

Russel G. Mitchell

ABSTRACT: Lodgepole pine frequently grows in mixture with other tree species. Some of the associates may be other host species of the mountain pine beetle--ponderosa pine, sugar pine, western white pine, whitebark pine--and some may be non-hosts. These mixtures often present special management problems. Specific rules are impossible for all the various combinations that can occur, but some general strategies are possible. Lodgepole pine is a tree that is rather common and is easily cultured on a wide variety of sites. It is also a tree that is very susceptible to mountain pine beetle attack. Accordingly, when lodgepole grows in mixture with other species, a good, general policy is to discriminate against lodgepole pine and manage the other species on the site. On a forest-wide basis, this is a step toward increased diversity. When combined with stocking-level control and management of age classes across the entire forest, the strategy becomes a two-fold management system--one for trees and one for the mountain pine beetle.

INTRODUCTION

The pattern of tree-killing in a mountain pine beetle outbreak is a tragedy sequence--like a Greek play. In the tradition of Greek tragedy, the central figure is a collaborator in its own misfortune; the very characteristic that makes the hero a hero is the same characteristic that ultimately propels him to a disastrous end. Also, once the plot is in motion, nothing--absolutely nothing--will keep it from moving to its fated climax. Here, the "hero" is a forest of mature, over-stocked lodgepole pine--sometimes mixed with other tree species and sometimes in nearly pure stands. The instrument of destruction is the mountain pine beetle.

The mountain pine beetle, unaware of its dramatic role, only does what all living things do--strives to convert as much of the environment as possible into itself and its progeny. A mature, overstocked lodgepole pine forest is ideal for that goal. The scene at the end of the outbreak is classic tragedy. The stage is covered with dead bodies; the lodgepole is dead (at least the larger trees), the beetles are dead, and a few associate tree species--like ponderosa pine, sugar pine, western white pine, and white bark pine--can also perish. Non-host species like larch and true fir, though, may profit from the outbreak. This paper describes some of the interactions of lodgepole pine growing with other tree species and discusses some considerations involved in managing these stands.

THE PROBLEM

In central Oregon, where I work, lodgepole pine often grows extensively in nearly pure forests and is considered climax forest, since little else grows there (Cochran and Berntsen 1973, Cochran 1984). But a large area that has been dominated by ponderosa pine will also support lodgepole pine. Accordingly, where and when conditions are right, lodgepole often invades the ponderosa pine stands. This pattern has increased in the last 75 years because of the effectiveness of the program to control wildfires. Before fire control, the fire frequency in ponderosa pine stands in central Oregon was 8 to 15 years (Bork 1984) and lodgepole pine, which is sensitive to even low-intensity fires, rarely survived long enough to produce seed.

Second-growth ponderosa pine is a well-documented host of the mountain pine beetle, mostly in over-stocked, poor-site (poorer than site III) stands (Sartwell and Stevens 1975). But lodgepole pine is relatively more susceptible. To date, the only significant beetle-kill in ponderosa pine in central Oregon has been where it is closely associated with lodgepole pine--most commonly where a concentration of beetles attracted to an individual lodgepole pine has been so great that the lodgepole pine could not accommodate all the beetles and the surplus killed a few adjacent ponderosa pines.

A more serious problem with ponderosa pine develops as outbreaks die out in local areas. When beetle populations are extremely high and the reservoir of preferred lodgepole pine is about exhausted, any associated ponderosa pine are in serious jeopardy of being attacked by a large number of beetles searching desperately for hosts. Most of the trees attacked are pole-sized ponderosa pine, but a few very large ponderosa pine may also be killed. The good news in this pattern (besides the fact that, usually, few large trees are killed) is that attacks on ponderosa pine signal the end of the outbreak in the area, usually within 2 years--a lot of beetles die in unsuccessful attacks and beetle survival is poor even in those trees that are killed. This pattern should not

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Russel G. Mitchell is Research Entomologist, Silviculture Laboratory, Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture, Bend, OR.

be confused with over-stocked stands of pure, pole-sized ponderosa pine; such stands can generate outbreaks independently, particularly on poor sites.

Sugar pine and western white pine are part of a more complicated mixture. Both species are associated with ponderosa pine as well as lodgepole pine; true firs may also be found in the white-pine mixture. The difficulty in managing these stands is that beetles seem to attack both sugar and white pine almost as readily as lodgepole pine. Attacks have been observed on some very large sugar pine and white pine, and beetle survival--because of the very thick phloem in these trees (Amman 1969)--appears to have been quite good.

An uncommon association, occurring only at the top of a few mountains (above 7,000 feet in central Oregon), is lodgepole pine and whitebark pine. In these areas, the trees are often fairly large in diameter but usually quite stunted; most trees are less than 20 feet tall. Bark and phloem on these trees are typically thin and beetle survival is usually so low that populations probably could not persist if beetles were not being supplied from the infested forest below.

When mixed with larch, true fir, and spruce, lodgepole pine can dominate the forest type or it can be subordinate in the association. Growth rates are often good in this association, and some of the largest lodgepole pine are found on these sites. An interesting feature of beetle attack in these stands is that trees are found and killed by the mountain pine beetle in the same pattern followed in stands where lodgepole grows closer together; trees over 12 inches DBH are nearly all killed, and the probability of attack drops off as tree diameter declines. Often the beetle-kill in these stands proves beneficial. Many stands dominated by larch apparently started out as a mixture of larch and lodgepole pine; the beetle, in this case, is a useful thinning agent.

MANAGEMENT STRATEGIES

Decisions in mixed species management must factor in several considerations, principally beetle biology, tree biology, and economics. Then, evaluation shifts to such questions as impacts on wildlife, grazing, and esthetics. Finally, the decision becomes a local one when the need for diversity enters into the process. Considerations range from intervention with chain saws to benign neglect--and many choices in between. Some of the features to be considered when a given blend of tree species are to be managed for tree growth and beetle management are outlined below.

Lodgepole pine/ponderosa pine

Some factors that enter into the management decision for the lodgepole/ponderosa pine type are:

- Lodgepole pine is more susceptible to attack by the mountain pine beetle than is ponderosa pine when the two species are growing together.
- Ponderosa pine is most susceptible on the poorest sites; it is not very susceptible on sites better than site IV. Lodgepole pine, on the other hand, seems to be about equally susceptible across all sites, once the outbreak is in motion.
- In outbreak situations, thinning to stocking levels of 60 to 80 square feet per acre provides beetle protection for both ponderosa and lodgepole pine, but it works better in ponderosa pine.
- When both species are managed at the same stocking levels on the same site, lodgepole pine will outgrow ponderosa pine for about 50 years (Dahms 1983). Also, lodgepole will produce a tree with less taper, less bark, smaller branches, and less sapwood.
- For rotations longer than about 80 years, ponderosa pine will outgrow lodgepole pine in volume and will produce larger trees that are more valuable (on a board foot basis) than small trees (Barrett 1979).
- If both species are to be managed on the same site, ponderosa pine must be planted; relying on natural regeneration through shelterwood, seedtree, or selection systems would mean that lodgepole pine would eventually dominate the site because of its superior seeding characteristics. Site treatments to correct the inbalance, such as prescribed fire, may be possible but would likely require heroic efforts.

After contemplating these points, the forester needs to ask whether more lodgepole pine is wanted. In central Oregon, we already have more then 500,000 acres of topo-edaphic climax lodgepole pine--stands where we can grow nothing else but lodgepole pine. Accordingly, a choice to discriminate against lodgepole pine, in stands where it is mixed with ponderosa pine, is a choice for increased diversity because lodgepole eventually dominates these sites if left alone. It is also a choice for more beetle resistance under appropriate stocking control and for rotations longer than 80 years. Finally, encouraging ponderosa pine makes economic sense. According to a simulation analysis by Znerold (1988), which factored in growth response and reduced beetle susceptibly, stocking control in second-growth ponderosa pine will produce a benefit/cost ratio of about 3 to 1. In the current economic climate, achieving that kind of ratio with lodgepole pine is unlikely.

Lodgepole pine/sugar pine/ponderosa pine

Ponderosa pine is less susceptible to mountain pine beetle than either sugar pine or lodgepole pine. Also, sugar pine seems to be slightly less suceptible to beetle attack than does lodgepole pine. Accordingly, the management approach to this type is similar to the mixed forest just mentioned--that is, encourage ponderosa pine and sugar pine. The question then becomes how much sugar pine to save. Because of the risk with sugar pine, the safest approach would be to strive for minimum acceptible stocking with ponderosa pine, then add sugar pine. Sugar pine is a fine tree from several perspectives. It offers diversity, and susceptibility to beetle attack would likely be lowered if the trees were well spaced and lodgepole pine eliminated from the stand.

Lodgepole/western white pine/true fir

The association of lodgepole/western pine/true fir also has some problems similar to those in the ponderosa/lodgepole type. An important difference, though, is that this mixture occurs at higher elevations (above 6,000 feet in central Oregon) and usually contains true firs as well as a few fast-growing ponderosa pine. Again, the philosophy is to strive for diversity along with beetle resistance. Diversity with resistance is accomplished by maintaining white pine, ponderosa pine, and true fir, but with a serious attempt to remove all lodgepole from the stand. If larch is present, it would be used too. The response of western white pine within this mixture is unknown. White pine is rather susceptible to the mountain pine beetle, and the risk of managing a stand containing western white pine(aside from blister rust) is that the tree will attract beetles into the stand and become a threat to the residual ponderosa pine. The risk may be worth taking, however; western white pine is a magnificent tree in just about every respect. Further, the ponderosa pine on sites where true fir grows is usually less susceptible to beetle attack than when it grows at lower elevations.

Lodgepole/whitebark pine

Management within lodgepole/whitebark pine stands is probably impractical just about everywhere. The trees are too stunted to have commercial value, and they already grow so far apart that thinning would be meaningless. Because of poor beetle survival, the populations in these trees appear to be non-sustaining. Thus, the best chance to improve the beetle situation in these stands would be to manage the lower elevation stands that seem to be supplying the beetles.

Lodgepole pine/larch/true fir/spruce

Very often the best management policy in lodgepole/larch/true fir/spruce stands, from the standpoint of the mountain beetle, is benign neglect. If the amount of lodgepole in the stand is less than 50%, letting the beetle kill those trees for the thinning effect is usually beneficial. Keeping lodgepole in the mixture and managing at stocking levels that would avoid significant beetle problems is also possible. The problem with this strategy is that the stocking levels needed to avoid the beetle in lodgepole are so low that the strategy does not even come close to capturing the capacity of the site to produce wood if it were managed for one or more of the non-host species. Accordingly, the decision is usually to eliminate the lodgepole pine and manage for larch, true fir, and spruce.

DISCUSSION

The key management pattern described above is obvious; discriminate against lodgepole pine but also strive for diversity within stands and across the forest. That strategy is closely followed by stocking control. The focus on discrimination stems from the fact that lodgepole pine is the most susceptible of the native western pines. The other reason for discriminating is that we have so much lodgepole pine and more can easily be grown--if we want it. Lodgepole pine usually will produce more progeny than any of its neighbors and do it year after year; its rapid juvenile growth means it will compete during the establishment period with most other plants; and its huge ecological amplitude lets it grow on a very wide range of sites, including some where nothing else will grow.

But lodgepole pine may be wanted on some of those sites; if so, it can be grown by managing the stocking levels. In the worst-case situation (a small island of thinned lodgepole in a sea of unmanaged lodgepole), the mortality rate even of large trees can be cut in half during an outbreak. For trees in the 6- to 9-inch DBH classes, survival is improved 4 to 5 times by thinning. The problem as noted above, though, is that if we manage for lodgepole in the mixture, the spacing is so wide that we are failing to capture a significant part of the sites productive capacity. Also, we do not know how long a thinning in lodgepole pine will endure. A biological limit must certainly control how long we can grow lodgepole pine, and the mountain pine beetle will probably dictate that length. But that limit is certainly longer in a stand where stocking level is managed--maybe a lot longer.

The important thing to remember about managing beetle-susceptible forests is that the mountain pine beetle is a FOREST pest. "Forest" is emphasized because we cannot manage 40 acres here and 40 acres there and expect much protection from the mountain pine beetle. Beetles build up in unmanaged stands and can fly a long way. And when beetle populations are large, they expand their food supply; trees that would normally resist

beetle attack at low or moderate populations are often overwhelmed at high populations. We must manage nearly all our forests, pure stands of lodgepole pine as well as stands of mixed species. When we do that, we are managing beetle populations as well as the forest. Then, with reduced opportunity for beetle populations to grow, we can introduce a little flexibility in our management style--perhaps take a few chances and grow an overstocked stand here and there; maybe increase the mix of sugar pine or western white pine; or let something go for a few years while we take care of some other high-priority problem.

The mountain pine beetle is a real pain. If we did not have it, we could probably lengthen our rotations, grow some rather sizable lodgepole pine, and improve the volume increment on many of our sites where we now have pine. But consider another possibility: perhaps the mountain pine beetle is really not a curse from the gods but a gift, sent to give us some direction on how to manage a whole forest for growth, diversity, and the best possible mosaic of age distribution and species composition. The mountain pine beetle is, in fact, another one of those things that makes forestry anything but a schedule of routine prescriptions; it is this kind of a problem that adds excitement to our professional lives and makes it fun to go to work in the morning. So the tragedy may not be that we have the mountain pine beetle, but rather that through poor focus on management needs, we have let the beetle get out of control.

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PREVENTIVE STRATEGIES FOR LODGEPOLE PINE/MOUNTAIN PINE BEETLE PROBLEMS: OPPORTUNITIES WITH IMMATURE STANDS

Dennis M. Cole

ABSTRACT: Culture of immature lodgepole pine stands is seen as a critical part of long-term prevention strategies for reducing future resource losses from the mountain pine beetle. This paper describes applicable practices for immature stands and discusses their strategic role in attaining a forest-wide mosaic of stands varying in age, size, composition, and structure. A diverse forest mosaic is considered necessary for avoiding severe mountain pine beetle outbreaks in commercial forests.

INTRODUCTION

Strategies to minimize losses to the mountain pine beetle (Dendroctonus ponderosae Hopk.) include a variety of practices that differ in intent and effectiveness. Some seek to reduce losses by prevention, some by recovery and utilization of otherwise lost trees, and others by amelioration of effects. A diagram classifying practices, intents, tactics, and strategies for controlling losses to the mountain pine beetle (MPB) in lodgepole pine (Pinus contorta var. latifolia) forests was developed earlier (Cole 1978). The practices discussed in this paper include those prevention tactics identified in that classification (fig. 1).

Although this topic associates strategies with stands, it is really the forest, over time, that we are concerned with in developing prevention strategies for reducing losses to the mountain pine beetle. This distinction focuses the generalized goal of reducing losses to the specific objective that will accomplish it--namely the management of endemic mountain pine beetle populations to prevent their increase beyond endemic levels. This means that strategies for immature stands must be developed and executed as an integral part of ongoing, long-term, forest-wide programs for managing the age, structure, composition, and vigor of stands--and their juxtaposition across the landscape--to keep mountain pine beetle populations endemic. Such programs will include (along with strategies for immature stands) silvicultural strategies for mature/overmature stands as discussed earlier in this symposium, and utilization and chemical intervention strategies to be discussed in following papers. The overview and field trip discussions of silvicultural and resource management strategies for addressing the mountain pine beetle problem on the Swan Lake Ranger District of the Flathead National Forest will illustrate and provide context for many of the points discussed in this and the other papers.

The objective of this paper is to review appropriate silvicultural practices and strategies for minimizing future resource losses from the mountain pine beetle, in relation to immature stands. The stand--and often the individual tree or tree type--is the focal point in applying most of the cultural practices discussed; but to emphasize the critical forest-wide perspective needed in this issue, the focus here will be on opportunities for increasing future forest diversity through management of immature stands. Such diversity benefits nearly every resource of concern and is particularly important in minimizing forest losses from insects and disease.

APPLICABLE STAND-TENDING PRACTICES

Cultural practices for immature lodgepole pine stands have been identified for years (Smithers 1961; Tackle 1961). More recently, their role in the battle against the mountain pine beetle has been described (Cole 1978; Cole and McGregor 1985; Safranyik 1982; Safranyik and others 1974). Several practices for immature stands can contribute to the avoidance of future outbreaks of the mountain pine beetle. They are:

- Improvement and Sanitation Cuts
- Manipulation of Stand Density, Composition, and Structure
- Early Stand Replacement

Although not large in number, the flexibility in scale, scope, and timing of these operations provides the manager with an effective set of tools for affecting future forest diversity.

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Dennis M. Cole is Research Silviculturist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Bozeman, MT.

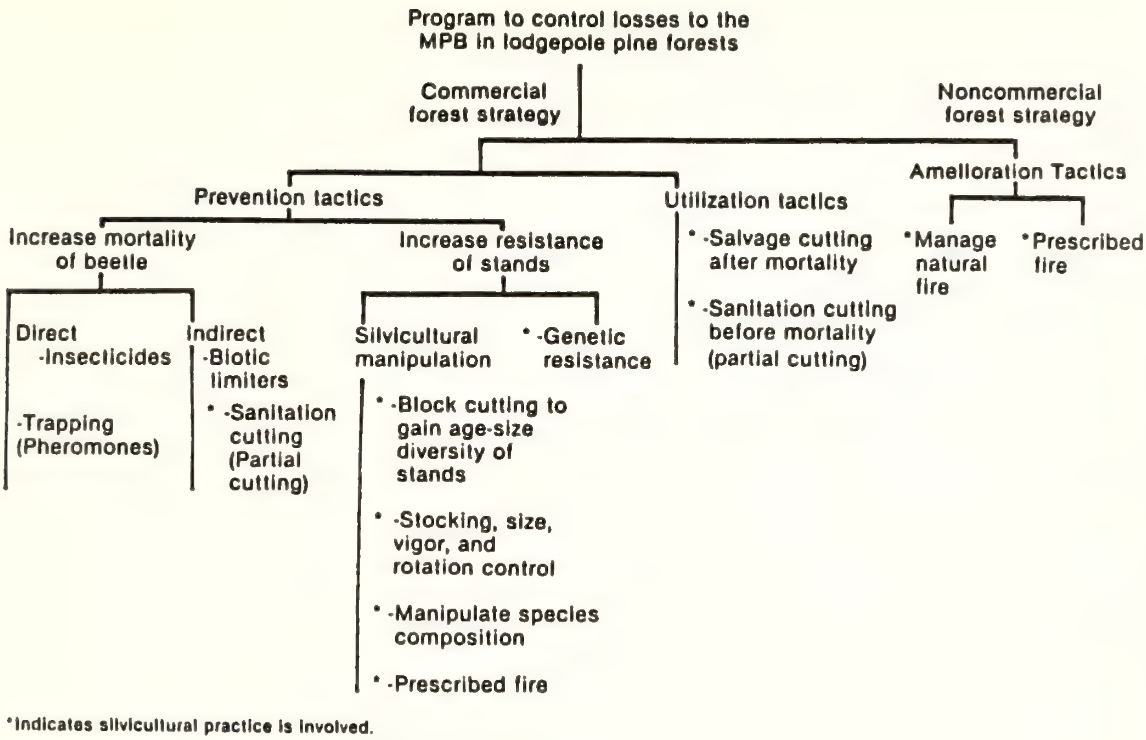

Figure 1--Place of immature-stand culture in strategies for controlling losses from the mountain pine beetle (from Cole 1978).

Improvement and Sanitation Cuts

Improved health of even-aged and uneven-aged lodgepole pine stands can be attained by stand tending keyed to detecting and removing diseased, damaged, or otherwise unhealthy trees. Many disease and damage effects occur in immature lodgepole pine stands (Krebill 1975; Lotan and Perry 1983); however, only lodgepole pine dwarfmistletoe (Arceuthobium americanum), wind, and snow warrant special mention. Stem rusts and root diseases can be locally debilitating in some lodgepole pine stands and predispose affected individual trees to bark beetle attack (Christiansen and others 1987), but effective control measures are not yet known (van der Kamp and Hawksworth 1985).

Dwarfmistletoe infection can predispose trees and stands to bark beetle attack by reducing tree and stand vigor. Ideally, dwarfmistletoe should be excluded from lodgepole pine stands in the regeneration phase of management. Where regenerated stands less than 20 years old occur with scattered infected residual trees from the previous stand, the infected residuals should be killed. In older infected stands, degree of infection should be determined (Hawksworth 1977), and thinning or partial cutting considered, for those stands not heavily infested. This will reduce infection levels and slow the decline in growth and vigor of the stand (van der Kamp and Hawksworth 1985).

Heavily infested stands approaching maturity, that have infected trees exceeding 8 inches d.b.h., should be partially cut to remove these beetle-attractive trees if sufficient growing stock remains for a reasonable yield at rotation. If growing stock would be insufficient, early replacement of the stand through regeneration harvest should be considered.

Wind and snow damage is common in immature lodgepole pine stands following thinnings or partial cuts, when the stand has been opened too much or extreme wind or snow has occurred. Wind damage can be minimized by adjusting thinning intensity to the exposure situation of the stand (Alexander and others 1983). Thinning adjacent to clearcuts where the prevailing wind angle approaches 90° should probably not exceed 40 percent of the basal area in a single entry (Schmidt and Barger 1987). Trees weakened by snow or wind damage are attractive to endemic mountain pine beetle and secondary bark beetles, and help mountain pine beetle populations survive at low levels and increase from those levels. Managers should pay close attention to heavily thinned stands, particularly those thinned from below, following heavy winds or snowfall. Obviously damaged trees should be removed promptly to deny them as breeding grounds for bark beetles, and to improve the general health and condition of the stand. Stands also can suffer unseen wind damage.

Trees that resisted wind-falling can suffer root damage from swaying and become attractive to bark beetles as a consequence (Christiansen and others 1987). Although such trees are difficult to detect until after-the-fact, bark beetles can detect them and focus attacks on them. Therefore, such stands, particularly those with size classes of lodgepole pine in or near them that are favorable for increasing mountain pine beetle populations, should be watched closely for several years following severe windstorms. Any trees colonized by bark beetles should be destroyed or removed from the stand before dispersal of broods from them.

In general, a forest-wide policy and program for stand improvement and sanitation of immature lodgepole pine stands will accomplish long-term benefits by reducing the number and severity of mountain pine beetle outbreaks. Mixed lodgepole pine stands, particularly those having a good representation of other species in the overstory, provide even more opportunities than pure stands for improvement cuts, for in them species discrimination against lodgepole pine can contribute to long-term reduction in mountain pine beetle hazard.

Manipulation of Stand Density, Composition, and Structure

The character and condition of immature stands can be greatly influenced by intermediate cuttings. Thinning appears to have the greatest potential for increasing or maintaining the vigor and growth of lodgepole pine trees and stands and thus contributing greatly to long-term prevention strategies for the mountain pine beetle (Cole and McGregor 1988). Both stocking control and intermediate thinnings are beneficial in this respect. Low thinning is the preferred thinning method for immature lodgepole pine, but the timing and spacing of thinnings to have a maximum effect on discouraging mountain pine beetle outbreaks are not yet clear. Early results from research studies (Mitchell and others 1983; Pitman and others 1982) and observations of operational thinnings in mountain pine beetle outbreak areas indicate that recently thinned older stands are passed over in the early stages of outbreaks, but might suffer some mortality in later stages when favorable host trees are depleted from surrounding unmanaged stands. Although larger trees in thinned areas still are vulnerable to epidemic mountain pine beetle populations, this does not disqualify thinning as a prevention practice.

Rather, the fact that even in outbreak situations thinned stands usually suffer a lower percentage of mortality of susceptible-sized trees, suggests that had thinning and other stand-tending practices been the norm rather than the exception the mountain pine beetle outbreaks might not have occurred (Cole 1978).

There is still debate as to whether the apparent benefit of thinning in reducing mortality from the mountain pine beetle is due to its effect on tree vigor or on the micro-environment influencing the beetle--or a combination of the two. Regardless of the exact and fundamental entomological explanation, thinning can be considered a valuable practice in long-term prevention silviculture for the mountain pine beetle problem. However, because too small a proportion of our lodgepole pine forests are likely to be thinned soon enough to fully succeed in prevention it is important that the fundamental effect of thinning on the mountain pine beetle be determined. Without this information, we do not know specifically how and when to thin or rethin stands approaching the mature stage. With this lack of knowledge we may delay mountain pine beetle outbreak by thinning, but set the stand up for even greater losses if the cause and duration of the thinning benefit are not thoroughly understood. With these uncertainties, what recommendations on type, intensity, and timing of thinnings, can be given for immature stands?

I believe the safest strategy at this time for pure immature lodgepole pine stands is to plan and execute an expanding program of thinning to accomplish stocking levels and growth rates that culminate and allow stand rotation at about 80 years of age (Cole 1975, 1978). The age, structure, and vigor of stands managed under this strategy are not considered to be highly susceptible to the mountain pine beetle (Amman 1978). When implemented on a forest-wide scale--with other factors (such as varied size and juxtaposition of stands) a richer forest mosaic can be created and hazard levels should be greatly reduced.

Another way of gaining diversity in the forest mosaic is through intermediate or repeated thinnings in older but still immature lodgepole pine stands. Culminated yields cannot be expected from such treatments at rotations of less than 120-140 years unless thinning intervals are 40 years or more (Cole and Edminster 1985). But it is questionable if such long thinning intervals can maintain tree and stand vigor at high enough levels to discourage mountain pine beetle outbreaks. Therefore, if low hazard is to be maintained in extended rotations, repeated light thinnings at 10-20 year intervals will probably be necessary, and less-than-culminated yields accepted at eventual rotation.

In mixed species stands, where there is a manageable alternative to lodgepole pine, diversity can be accomplished by manipulating species composition and stand structure in the course of thinning immature stands. Discrimination against lodgepole pine in these situations also allows for longer rotations than is safe with lodgepole pine, thus providing additional levels of an important factor for varying the forest mosaic.

In addition to reducing potential for future losses to the MPB, there are other opportunities and amenities that can result from thinning. Thinning patterns to enhance or achieve greater forest diversity can benefit other resource values and thus in many cases be largely justified by those objectives alone. As an example, thinning prescriptions can be designed to affect species composition and canopy development and modify hiding, thermal, and forage cover ratios important to wildlife. Water quality and yield are also important values justifying the creation of thinned stand patterns in high-elevation lodgepole pine forests.

Early Stand Replacement

Overall forest diversity can also be promoted by another practice applicable to immature stands--early stand replacement. Overstocked stands, or portions of them, can be clearcut for round-wood products and firewood or simply trampled and burned in place. Varying the timing and spatial arrangement of these treatments, in conjunction with species choices in the regeneration of the site, will help in attaining greater age class, stand size, and species diversity in our lodgepole pine forests. In the following section, the importance of planning in increasing immature stand and overall forest diversity is discussed.

PLANNING FOR INCREASED FOREST DIVERSITY

The scope and intensity of recent mountain pine beetle outbreaks show the difficulty of trying to prevent or limit the effects of outbreaks when there is a preponderance of mature and overmature stands--and when only a small proportion of the stands have benefitted from stand culture. Failure to use all opportunities to achieve an improved mosaic of age classes, species composition, and stand sizes of lodgepole pine stands in the next several decades will almost surely result in another cycle of serious losses to the mountain pine beetle. Otherwise-sound silvicultural prescriptions, determined on a stand-by-stand basis, will not greatly improve the situation unless they contribute to greater forest diversity. To accomplish that they must be determined in a much wider context than has usually been the case.

The good news is that several factors have evolved to the point where they facilitate and justify prevention prescriptions and programs that until recently were not feasible. Among these are: (1) the improvement in multiresource data bases, (2) the demand for a better balance in resource protection and productivities, (3) the widening public recognition that costs for prevention of resource losses are good investments, and (4) recent advances in computer-aided technologies. The data base and computer technology advances are especially significant: they provide breakthroughs in mapping land, forest cover, habitat, and stand types, and in analyzing phenomena planned or occurring therein. Known as geographical information systems (GIS), the more advanced of these systems are able to integrate a variety of map projection data formats with associated resource data bases to produce a huge array of analyst-chosen resource maps. Among the capabilities of these systems are several that have great value for planning and managing our forests for prevention of mountain pine beetle outbreaks:

- *The ability to identify locations meeting analyst-specified criteria.* Maps showing the scope and spatial distribution of all lodgepole pine stands--by land type, habitat type, successional role, and stand type--in a National Forest or region, would be an example of this.

- *The ability to assess impacts.* Effects wrought by the mountain pine beetle or programs designed to prevent mountain pine beetle effects can be evaluated visually and statistically. Information from a variety of sources--such as biological relationships, rules of thumb, expert opinion, management policy--can be combined in one or more steps to produce the desired impact estimates. The use of GIS to assess mountain pine beetle impacts on the Butte Ranger District of the Deerlodge National Forest, as described earlier in this symposium, demonstrates that this technology is already being brought to bear on the mountain pine beetle problem in the area of resource impacts.

- *The ability to preview and assess trade-off options.* Responding to mountain pine beetle epidemics or taking long-range steps to prevent them involves the balancing of impacts on different resource values. By providing spatial representations of different trade-off decisions for various future time periods, an optimum strategy for the criteria used can be identified.

- *The ability to integrate the above capabilities.* Advanced systems integrate their major features, thus solution values from each routine are available to the other routines to allow updating of management alternatives at chosen future time periods.

CONCLUSIONS

Taken together with our considerable ecological knowledge of host and pest, the exciting new capabilities in spatial analysis, and the increased public desire for reducing resource losses, it appears safe to say that we are on the threshold of a new era of forest-wide resource protection and management through silviculture. A good start in attaining desirable forest diversity has already occurred

through the cutting and regeneration patterns of the past 40 years--and now through a variety of intermediate and harvest cutting practices precipitated by recent MPB outbreaks, or the threat of them. Increased silvicultural management of immature stands can play a central role in reducing future resource losses caused by the mountain pine beetle.

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UTILIZATION OPPORTUNITIES FOR REDUCING MOUNTAIN PINE BEETLE DAMAGE IN LODGEPOLE PINE

Carl E. Fiedler

ABSTRACT: The "window of opportunity" for utilizing dead lodgepole pine for most high-value products is less than five years. Consequently, management focus during beetle epidemics is on salvaging dead and threatened trees. Thinning to increase tree vigor and regeneration cutting to develop species and age-class diversity are silvicultural strategies for reducing losses in the future. Broad-scale application of these strategies is dependent upon utilization opportunities, especially for subsawtimber-size trees. Ironically, a proposed multi-product manufacturing facility that would utilize small trees for high-value products is currently on hold. Social and administrative factors hinder assurance of a dependable supply of raw material for the plant, despite an excess of small timber in the procurement area.

INTRODUCTION

Not so long ago, lodgepole pine (Pinus contorta Dougl. ex Loud.) was considered little more than a weed that got in the way of real trees. As recently as the 1960's, Hutchison (1964) noted that "the popular impression of lodgepole pine is of a skinny tree growing out on the edge of nowhere." But times change, and several situations have developed to increase interest in utilization of lodgepole pine. First, a dwindling old-growth timber supply in the West has gradually shifted emphasis toward increased utilization of smaller diameter material such as lodgepole pine. Second, and probably more important, the mountain pine beetle (Dendroctonus ponderosae Hopkins) epidemic that is devastating large areas of lodgepole pine in the northwestern United States and western Canada has heightened interest in utilization opportunities for dead or threatened lodgepole. In addition, because it is lightweight, has small, tight knots and desirable drying characteristics, lodgepole pine has come to be recognized as a quality lumber species. The purpose of this report, then, is to present current opportunities to use lodgepole pine (live and dead) for solid products, reconstituted products, or energy.

Paper presented at the Symposium on the Management of Lodgepole Pine to Minimize Losses to the Mountain Pine Beetle, Kalispell, MT, July 12-14, 1988.

Carl E. Fiedler is Research Silviculturist, Montana Forest and Conservation Experiment Station, School of Forestry, University of Montana, Missoula, MT.

CONSTRAINTS ON UTILIZATION

Timely utilization of beetle-killed or threatened lodgepole pine is complicated by several factors. First, large volumes of material suddenly become available for utilization, with little advance notice. Consequently, timber harvest schedules must be altered and traditional planning horizons shortened. This situation has also forced land managers and the forest products industry to look for new utilization opportunities. From the standpoint of utilization for most products, beetle-infested stands represent a classic "use it or lose it" proposition.

Beetle epidemics leave public land managers in an especially untenable position. On the one hand, managers must contend with large volumes of dead or threatened timber; yet they have only a short "window of opportunity" to utilize this material for high-value products. They also are faced with various nontimber resource constraints and limited utilization opportunities. Furthermore, the more organizational resources that are directed at salvaging beetle-killed material, the less are available for other stand management needs.

Mountain pine beetle epidemics also leave the forest products industry in a difficult position. The sheer volume of lodgepole pine killed by beetle attacks often exceeds both the capability of the industry to recover this material and the capacity of mills in the area to utilize it for high-value products. While the temporary glut of raw material caused by beetle epidemics may benefit the timber industry in the short run; it has serious timber supply implications in the long run, since most of the lodgepole pine type is in public ownership (Barger and Fiedler 1982). Accelerated harvest in certain locations now may limit raw material availability in the future because of hydrologic constraints and wildlife concerns.

Mountain pine beetle epidemics affect long-term timber supply in another more insidious way. Scattered, standing-dead trees that have died from such endemic causes as suppression, lightning, or root rot are usually not included in forest inventories, and therefore are not included in allowable cut calculations. To the extent that these trees are salvaged in green timber harvest operations, they are excess supply. Conversely, the many thousands of trees killed in stand-level mortality events (e.g. mountain pine beetle epidemics) have been counted in green timber forest inventories, and therefore included in allowable cut calculations. To the

extent that this mortality is not salvaged and utilized, allowable cut allocations will have to be reduced in the future. Some organizations (e.g., Montana Department of State Lands, USFS Northern Region) have attenuated the impact of this potentially severe problem by adjusting yield table volumes downward based on projected mortality to the mountain pine beetle.

UTILIZATION-MANAGEMENT RELATIONSHIPS

A variety of management strategies exist to reduce mountain pine beetle losses in both immature and mature stands. Application of most silvicultural strategies, however, depends on markets for material removed in harvest treatments. Without profitable utilization opportunities, the manager has little flexibility to reduce susceptibility in immature stands, to recover dead or threatened material in mature stands, or to control the composition and density of regeneration following stand replacement.

Management strategies that involve timber harvest to reduce losses can either take the form of thinning treatments, regeneration cuttings, or sanitation-salvage operations. Thinning treatments are usually applied to immature sapling- and pole-size stands to increase leave-tree vigor and decrease susceptibility to mountain pine beetle attack. This appears to be an especially effective strategy in younger stands for reducing long-term losses to the beetle. Trees removed in thinning are usually smaller than the mean stand diameter, so primary utilization opportunities, if any, are for small roundwood products or reconstituted products. With limited utilization opportunities for small trees, however, managers have been unable to apply intermediate treatments as needed. Preventive thinning treatments may have limited applicability in areas where much of the lodgepole pine is mature and of sawlog size.

Application of regeneration cutting to develop a mosaic of species and age classes is another form of preventive treatment. Again, lack of demand for the subsawtimber component of harvested stands often means that smaller trees must be treated as a residue, at added cost.

Once an epidemic is underway, the primary means of reducing losses in middle-aged and mature stands is through recovery, rather than prevention. Recovery can be accomplished through sanitation-salvage cutting in stands where the infestation is not yet severe, and by regeneration cutting where it is. In either case, dead trees and those in imminent danger of attack are harvested while they still have value for products. Dead trees removed in salvage operations are usually larger than the mean stand diameter, so primary utilization opportunities include houselogs, studs, plywood, and reconstituted products.

Losses to the mountain pine beetle could theoretically be eliminated if all dead trees were utilized while they still had wood quality and appearance characteristics appropriate for their highest potential end use. In reality, managers are unable to keep up with the large volumes and broadly dispersed nature of mortality in beetle epidemics. Under these conditions, raw material supply is a transitory rather than a reasonably stable inventory quantity. Recovery must be rapid if dead trees are to be used for products with strict wood quality specifications, but can be extended somewhat if trees are used for most reconstituted products (with the exception of waferboard and oriented-strand board) or energy purposes.

Unfortunately, the value of dead lodgepole pine for products is generally inversely proportional to the "window of opportunity" for utilization. For example, dead lodgepole pine are usable for such high-value products as veneer for only 1 year (Snellgrove and Ernst 1983), and utility poles for 0 (Brown 1988) to 5 years (Tegethoff and others 1977). Dead trees can be used for moderate-value products such as studs for up to 4 years (Dobie and Wright 1978; Sanders 1988). Dead trees are usable in the manufacture of oriented-strand board for less than 1 year without wetting, and up to 4 years with specialized provisions for wetting (Koch 1988). Utilization for low-value uses such as pulp extends at least 7 years (Lowery and others 1977), and for energy at least 15 years.

UTILIZATION OPPORTUNITIES

Essentially all of the wood fiber comprising either immature or mature lodgepole pine stands is potentially usable. Its underutilization is a result of one or more of the following factors: limited demand, limited road access, management constraints, high logging costs, low product value, distance to primary markets, and limited rail service (Fiedler and others 1988). The value use of wood, defined by Keegan and Jackson (1986) as the amount a user is willing to pay for delivered wood over the long-term, strongly influences utilization opportunity. For example, delivered value use (table 1) can be compared to delivered cost (table 2) at the processing facility to estimate utilization potential for various stem size-product/use combinations. The "value use" versus "cost" comparisons provide only relative utilization potential. Tree size and wood quality characteristics obviously limit potential roundwood and sawn product uses (e.g., 4-inch diameter trees cannot be used for studs, and 16-inch diameter trees cannot be used for fence rails). In addition, while value use for such products as grape stakes, posts, and fence rails is high, demand is limited relative to the huge supply of small-diameter material. Koch (1987) estimated that over one third of the total volume of lodgepole pine is in trees less than 7 inches in diameter. Because small trees are so costly to harvest (table 2), high-value uses other than those mentioned above will have to be developed if significant volumes of subsawtimber size trees are to be utilized.

Consumer tastes also have a significant effect on utilization, especially for specialty products. Utilization of lodgepole pine for such tradi-

Table 1--Estimated delivered value use of wood fiber in the Inland Empire for solid products, reconstituted products, or energy (1984 dollars).[1]

Product or use	Value
	[2]($/cu. ft.)
Solid products	
Houselogs	.93-1.30
Studs	.60- .90
Posts and poles	.50- .80
Reconstituted products	
Particleboard	.15- .42
Fiberboard	.30- .80
Waferboard	.40- .80
Pulp and paper	.40- .80
Energy	
Fuel oil	.00- .70
Natural gas	.00- .65
Coal	.25- .35

[1]Adapted from Keegan (1987).
[2]One cubic foot of wood equals 25 lbs. (ovendry basis).

Table 2--Average mill-delivered cost of 3-in.- to 18-in.-diameter lodgepole pine. Costs include felling, skidding, loading, and hauling.[1]

Stem size	D.b.h.	Cost
(cu.ft.)	(in.)	($/cu.ft.)
1-2	3-4	.80-1.00+
2-10	4-8	.52- .80
10-30	8-12	.29- .52
30-70	12-18	.24- .29

[1]Costs were derived from Jackson and others (1984) based on the following assumptions: felling with a feller-buncher, 500-foot one-way skidding with a rubber-tired grapple skidder, and a 50-mile one-way hauling distance. These costs are averages based on a broad range of operating conditions.

tional products as studs and reconstituted products is fairly predictable over the long term, with fluctuations in demand due mainly to national economic cycles. Utilization for specialty products (e.g., houselogs, blue-stain paneling) is also affected by economic "times," but in addition is subject to changing and unpredictable consumer tastes. For example, the popularity of log homes has increased over the last decade, and with it the demand for houselogs. Both the log home market and the demand for houselogs remain strong (Montana Extension Service 1988). Conversely, decorative paneling manufactured from beetle-killed trees and marketed as "blue-stain pine" was a popular item in the late 1970's and early 1980's. However, both raw material supply and consumer demand have since declined in most areas where this product was manufactured and marketed (Ostermann 1988). Despite this short-lived popularity, blue-stain paneling provides a good example of the potential of innovative marketing to increase utilization levels over those for traditional products or uses alone.

RECENT DEVELOPMENTS

The earlier discussion assesses the potential for utilizing either the green trees removed from immature stands or the dead or threatened trees removed from mature infested stands for the manufacture of traditional products. A recently developed proposal for an integrated, multi-product manufacturing facility in northwestern Montana would provide for large-scale utilization (155,000 tons annually, ovendry basis) of lodgepole pine for both traditional and nontraditional products (Koch and others 1988). Raw material for the proposed plant would come from regeneration cuttings, sanitation-salvage operations, and preventive thinning treatments. Some of the material would be used in the manufacture of two products not heretofore produced in either the northwestern United States or western Canada, namely edge-glued lumber panels and fabricated pole joists. Both of these high-value products are made from dowels machined from subsawtimber-size lodgepole pine trees.

A notable anomaly emerges in considering the feasibility of the proposed plant, and one that is central to the problem of utilization as it relates to reducing mountain pine beetle losses. Despite the large acreage of both older, stagnated stands and beetle-infested stands within the proposed procurement area for the plant (75-mile radius), available raw material supply may not be sufficient for the planned 20-year life of the mill. Concern about a dependable long-term supply may seem absurd in light of the ongoing beetle epidemic and existing 105,000 acre supply (Koch and others 1988) of stagnated, marginal sawlog, and dead sawtimber stands within the procurement area. In this situation, concerns about supply might be likened to the old saw "water, water, everywhere, but not a drop to drink." However, past regeneration cutting coupled with recent heavy cutting to recover dead and threatened trees may bump up against cumulative effect constraints, effectively limiting large-scale harvest well into the future. Thus, attempts to reduce losses to the mountain pine beetle through utilization may be stymied, despite both demand for the raw material and an excess of supply. The root of the problem at this point is no longer a biological or technical one, but rather a social and administrative one.

A fairly recent development in the field of harvesting technology, namely helicopter logging,

also has potential for reducing losses to the mountain pine beetle. Helicopters can be used for salvaging large-diameter, dead and threatened trees in steep terrain where visual constraints or road-building costs may prohibit conventional logging. However, most of the following requirements have to be met for this approach to be feasible for harvesting lodgepole pine (Kinghorn 1988; Sanders 1988):

1. Local demand for raw material must be strong.
2. Stumpage costs must be low.
3. Sale volume should be 500 thousand board feet (MBF) or greater.
4. Harvested trees should average 9 to 10 inches in diameter or larger.
5. Flight distance from woods to landing should be one-half mile or less.
6. Small, maneuverable, and cheap helicopters (e.g., Lama) should be used rather than larger, costlier ones (e.g., Skycrane).

While helicopter logging has been used almost exclusively to harvest large-diameter, high-value trees (e.g., yellow pine [Pinus ponderosa Dougl. ex Laws.] for sawlogs; western redcedar [Thuja plicata Donn] for shakes), it has also been used in several specialized situations to salvage beetle-killed lodgepole pine in steep terrain. Harvest costs in the log deck typically range from \$100 to \$160/MBF, which is similar to skyline logging with intermediate supports (Sanders 1988). Helicopter logging appears to have increased potential in the future as managers become more aware of the specific timber sale design features necessary for its successful application.

SUMMARY

Management focus during a mountain pine beetle epidemic is necessarily on salvaging mortality, since the "window of opportunity" for utilizing dead trees for most high-value products is less than five years. However, the long-term solution to the beetle problem will probably not come until there are sufficient utilization opportunities and product values for the smaller material removed in preventive silvicultural treatments. Regeneration cutting aimed at liquidating stagnated stands or breaking up extensive areas of uniform age classes, or intermediate treatments aimed at increasing tree vigor, will only be carried out on a broad scale if such treatments can pay their own way. Even then, as a recent example in northwestern Montana has shown, the ability of managers to capitalize on large-scale utilization opportunities to reduce mountain pine beetle losses may depend more on social and administrative factors than on technical or biological ones.

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EFFICACY OF VERBENONE FOR PREVENTING INFESTATION OF HIGH-VALUE LODGEPOLE PINE STANDS BY THE MOUNTAIN PINE BEETLE

Richard F. Schmitz

ABSTRACT: Results from experimental deployment of the mountain pine beetle (MPB) (Dendroctonus ponderosae Hopkins) semiochemical verbenone, an antiaggregative pheromone component, suggest it may be useful for preventing or suppressing MPB infestations in high-value lodgepole pine stands (Pinus contorta var. latifolia Dougl.). Field measures of the response of MPB to funnel traps baited with the standard MPB lure (trans-verbenol, exo-brevicomin, and myrcene) in Utah showed a 98 percent reduction in MPB trapped when verbenone was added. When used experimentally to protect 1-ha lodgepole pine stands in Idaho from further MPB infestation, the treated stands had an average reduction of 48.6 percent in the number of infested trees. Comparable findings have resulted from similar tests conducted in Canada.

INTRODUCTION

There is an obvious need for environmentally acceptable suppression strategies that protect high-value lodgepole pine stands, such as those in travel influence zones, campgrounds, and riparian areas, from infestation by the mountain pine beetle (Dendroctonus ponderosae Hopkins) (MPB). This need has prompted investigations to determine how semiochemicals like verbenone might be used to suppress MPB populations. As a result, the effectiveness of suppression strategies utilizing synthetic semiochemicals to manipulate dispersing mountain pine beetle populations is being field tested to determine how these natural compounds should be deployed to prevent infestation of high-hazard stands (Amman and others, in press; Borden and others 1983; 1987; Lindgren and others, in press). To that end, representatives of the U. S. Environmental Protection Agency (EPA) agree that semiochemicals may be preferable to conventional pesticides in the management of insect pests and encourage their development and use (Booth 1988).

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Richard F. Schmitz is Principal Entomologist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Ogden, UT.

Earliest efforts to exploit semiochemicals for suppression purposes concentrated on the attractive components that guide flying beetles to suitable hosts. As a result, most field tests were designed to evaluate the most effective deployment of these attractive elements to lure and concentrate beetles in stands targeted for harvesting. Results revealed that beetle populations attracted to baited stands often "spilled over" into surrounding unbaited stands that land managers intended to protect (Furniss 1972). At the same time, field tests to evaluate the function of each newly isolated component in a specific pheromone bouquet revealed that bark beetle pheromone systems contained an anti-aggregative component (Borden 1982). In general, these components appear to function as a mask that terminates response to the attractive elements, thereby ensuring that the density of attack does not exceed the threshold for optimum brood survival (Borden and others 1987).

SOURCE AND EFFECTIVENESS OF MOUNTAIN PINE BEETLE ANTIAGGREGATIVE COMPONENTS

Verbenone was identified and first isolated from the mountain pine beetle pheromone complex, using the hindguts of newly emerged and feeding female MPB, by Pitman and others (1969). It was also identified from air passed over emergent male/female pairs (Rudinsky and others 1974). The first evidence that verbenone had antiaggregative properties resulted from laboratory and field bioassays that showed (-)-verbenone inhibited MPB response to selected host- and beetle-produced volatiles (Ryker and Yandell 1983). Additionally, four other pheromone components isolated from the MPB pheromone have at times exhibited anti-aggregative properties. These include endo- and exo-brevicomin released by attacking males (Libbey and others 1985; Rudinsky and others 1974; Ryker and Rudinsky 1982), frontalin produced by feeding males (Libbey and others 1985; Ryker and Libbey 1982), and verbenone and pinocarvone produced by feeding beetles of both sexes (Libbey and others 1985).

Recent field tests in British Columbia (Borden and others 1987), using two release rates of endo-brevicomin, failed to confirm the concentration-dependent multifunctional attractive and antiaggregative qualities reported by Ryker and Rudinsky (1982). Similarly, field tests in Oregon (Libbey and others 1985) failed to substantiate the multifunctional properties of exo-brevicomin, confirming its antiaggregative qualities at high

release rates but failing to demonstrate attractive properties at low rates. When used as a tree bait, it elicits a host-specific response. On western white pine, Pinus monticola Dougl. ex. D. Don, it inhibited MPB attack (McKnight 1979; Pitman and others 1978), but on lodgepole pine, P. contorta var. latifolia Dougl., attack was enhanced (Borden and others 1983; McKnight 1979). Field tests of frontalin in Oregon revealed it had antiaggregative effects at high concentration (Rudinsky and others 1974) but induced attack on lodgepole pine in Idaho (Chatelain and Schenk 1984). Trapping experiments in which pinocarvone was added to MPB lure reduced the catch by 50 percent (Libbey and others 1985).

ROLE OF VERBENONE IN HOST COLONIZATION

Results to date suggest the primary antiaggregative semiochemical that regulates MPB response to its host is (-)-verbenone. It has been recorded from three sources: (1) female beetles (Pitman and others 1969), (2) auto-oxidation of alpha pinene to cis- and trans-verbenol, then to verbenone (Hunt and others 1988; Lindgren and Borden, these proceedings), and (3) oxidation of cis- and trans-verbenol by microorganisms (primarily yeasts) associated with the beetle (Hunt and Borden, in press; Lindgren and Borden, these proceedings).

A complete understanding of the interaction between pheromone components that regulate MPB host selection behavior requires all components be identified and tested at appropriate concentrations in the field. To date, 33 semiochemicals have been isolated from the beetle (Lindgren and Borden, these proceedings), and they often elicit conflicting responses from the beetle, depending on test concentrations and methods of deployment (Lindgren and Borden, these proceedings). The following conceptual model proposed by Borden and others (1987) summarizes what is known about the sources of verbenone, the onset of production in relation to the sequence of attack, and its probable role in regulating the duration and density of attack.

At the onset of attack by female MPB, volatiles (including the host monoterpenes alpha-pinene and myrcene together with female-produced trans-verbenol) attract additional beetles to the tree. As males reach the tree, they release exo-brevicomin, which initially attracts primarily females, thereby enhancing the level of attraction. As additional males colonize the tree, concentrations of exo-brevicomin increase and are augmented by the male-produced antiaggregant, frontalin. Simultaneously, concentrations of the aggregative components, trans-verbenol, and the host monoterpenes begin to decline. At this stage in colonization, it is believed verbenone levels produced by (1) auto-oxidation of the host monoterpene, alpha pinene, to cis- and trans-verbenol and then to verbenone, and (2) by conversion of cis- and trans-verbenol by microorganisms, reach concentrations that deter additional beetles from attacking the focus tree. The effect of these antiaggregants is to limit attacks to a density that ensures survival of the ensuing brood.

VERBENONE FIELD TESTS

Reducing Response to Attractive Traps

During the summer of 1986, entomologists from the Intermountain Research Station, in cooperation with personnel from Phero Tech Inc., Vancouver, BC, conducted tests in the Wasatch National Forest in Utah to compare the number of MPB attracted to the standard MPB lure (trans-verbenol, exo-brevicomin, and myrcene), with and without verbenone (Schmitz and McGregor, in press).

Methods--The MPB lure contained trans-verbenol, exo-brevicomin, and myrcene eluted at 2 mg/24 h, 0.2 mg/24 h, and 18 mg/24 h at 25 °C, respectively. Verbenone was contained in the standard plastic bubble cap and released at 5 mg/24 h/capsule at 25 °C. The test was conducted in a mature lodgepole pine stand surrounded by stands in which MPB populations were building to outbreak levels. The eight test blocks were 30 m square and were separated from one another by 30-m intervals. Funnel traps were hung at each of the four corners of a block. The four treatments--MPB lure, MPB lure with verbenone, verbenone alone, and empty trap--were randomly assigned to each of four positions. Effectiveness of verbenone as an antiaggregant was assessed by the number of MPB caught by treatment.

Results--A total of 1,130 MPB were trapped by the four treatments. Results by block are given in figure 1. The number and percentage caught by treatment are tabulated below:

	Number	Percent
MPB lure alone	1,083	95.8
MPB lure with verbenone	19	1.7
Verbenone alone	7	0.6
Unbaited trap	22	1.9
Total	1,130	100.0

The number of MPB responding to the MPB lure with verbenone was significantly less than to the MPB lure alone. Overall, the addition of verbenone to the synthetic MPB lure reduced the catch by 98 percent.

A field test of MPB response to synthetic semiochemicals in British Columbia revealed that when verbenone was released in funnel traps at 1 or 5 mg/24 h in the presence of the attractive synthetic MPB lure (trans-verbenol, exo-brevicomin, and myrcene), it reduced the response of males approximately 75 percent. Although not statistically significant, the reduction in female response followed a similar trend (Borden and others 1987).

Protecting Stands from Infestation

The encouraging results from the studies that used verbenone to suppress catch of MPB in traps prompted a second set of tests to determine the efficacy of verbenone for reducing MPB infestation

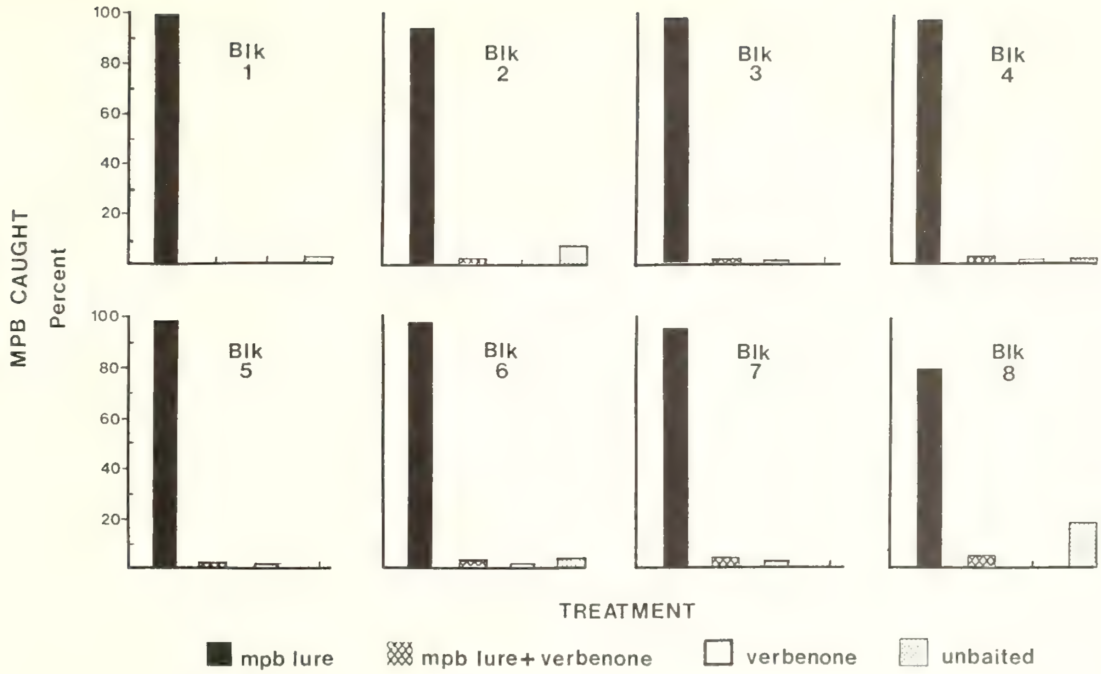

Figure 1--Number of MPB responding to funnel traps baited with synthetic MPB lure and the antiaggregant verbenone, alone and in combination, in eight test blocks, Wasatch National Forest, 1986.

in selected stands of lodgepole pine (Amman and others, in press). The test was conducted in the Sawtooth National Recreation Area, ID, while similar tests by Lindgren and others were being conducted in British Columbia, during 1987.

The Sawtooth National Recreation Area was selected for the study because MPB populations in that area were rapidly increasing, providing an opportunity to test the effectiveness of verbenone for preventing infestation of high-value trees in campgrounds, near administrative sites, wildlife sites, and near summer homes. Lodgepole pines 15.2 cm and larger diameter at breast height (d.b.h.) averaged 20 cm d.b.h. and 144 years old. The stand consisted of 75 percent lodgepole pine; the remainder was mostly Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco) and a few quaking aspen (Populus tremuloides Michx.). The ratio of infested trees from 1985 to 1986 was 1:8. A survey through the main part of the infestation revealed 57 newly infested trees per hectare. Eighty percent of these were 20 cm and larger d.b.h., those sizes of trees in which MPB reproductive success is best (Cole and others 1976).

Methods--Verbenone was eluted from the standard plastic bubble cap at 5 mg/24 h/capsule at 25 °C in the presence of the MPB tree bait. Constituents of the MPB lure were the same as those used in the earlier trap tests (trans-verbenol, 2 mg/24 h; exo-brevicomin, 0.2 mg/24 h; and myrcene, 18 mg/24 h, at 25 °C). Treatments consisted of (1) MPB tree lure, (2) verbenone, (3) MPB tree lure and verbenone, and (4) check. Each treatment was applied individually to 1-hectare blocks and replicated four times. Five MPB tree baits were used in each baited block.

The cardboard containing the MPB lure was stapled 2 m above ground level on the north side of a lodgepole pine 20 cm or larger d.b.h. (fig. 2a). MPB tree lures were distributed in the center of the block and at each cardinal direction from the center, approximately 20 m from the outside boundary of the block.

Verbenone-treated blocks had 100 verbenone bubble capsules obtained from Phero Tech Inc., Vancouver, BC (chemical purity 98.6 percent; optical purity ee = (-)72 percent), spaced in a grid pattern approximately 10 m apart. The capsules were stapled to the north sides of trees 2 m above ground (fig. 2b). In the blocks treated with MPB tree bait plus verbenone, baits and verbenone bubble capsules were distributed as described for each alone. Check blocks were untreated.

All lodgepole pines larger than 15.2 cm d.b.h. were examined in each block to determine the d.b.h. and number killed for the years 1986 and 1987. Treatment effects were assessed by comparing the percentage of all lodgepole pine 15.2 cm d.b.h. and larger in each block that was infested by MPB in 1987. Because stand characteristics have been shown to affect mountain pine beetle infestation behavior (Cole and Amman 1980), stand measurements were made on five 10-factor basal area plots in each treatment block. Plots were positioned so overlap did not occur--one at block center and one in each corner. All trees 12.7 cm d.b.h., regardless of species, were tallied. These data were used to calculate percentages of trees that were lodgepole pine, average d.b.h. of lodgepole pine, stand basal area, and crown competition (Krajicek and others 1961) to be analyzed by ANOVA for differences among treatments.

Figure 2--Dispensers from which MPB lure and verbenone were released: (A) paper container with plastic vials containing the three-component attractive lure, (B) verbenone bubble cap with paper sunshade to limit exposure to solar radiation.

Results--A significant difference in percentages of infested trees among treatments was shown by ANOVA. Blocks having MPB baits only had significantly more mass-attacked trees than other treatments. The effect of verbenone is apparent.

The average percent of lodgepole pine infested by mountain pine beetles in blocks treated with mountain pine beetle tree baits and verbenone is shown here:

	MPB tree bait present	MPB tree bait absent
Verbenone present	7.425	0.875
Verbenone absent	24.425	3.275

Verbenone in the presence of mountain pine beetle tree bait resulted in a 2.3-fold reduction in infested trees.

An examination of the percent change in numbers of MPB-infested trees between 1986 and 1987 for the four treatments shows that only in verbenone-treated blocks did an average reduction occur (-48.6 percent). However, despite the overall reduction, an increase occurred in three of the four blocks. Check stands showed either no change or a decline in three of the four blocks, with a large increase in the fourth block. However, the average increase was 64.7 percent from 1986 to 1987. Changes in infestation in verbenone-treated and check blocks were small when compared to baited blocks, which showed an average infestation increase of 2,575 percent. Blocks containing MPB baits and verbenone had an average infestation increase of 418.8 percent. The large difference in MPB infestation between MPB bait blocks and MPB bait plus verbenone blocks is considered due to the effect of verbenone. This suggests verbenone has considerable potential for reducing infestation of lodgepole pine stands, a conclusion also reached from tests by Lindgren and others (in press) in British Columbia.

Further, infestation differences probably were not related to differences in stand characteristics, since ANOVA failed to detect differences among treatments in percent of trees that were lodgepole pine, d.b.h. of lodgepole pine, basal area, and crown competition factor.

Discussion--Although verbenone-treated blocks had significantly fewer infested trees than blocks with MPB baits, the question remains: Would verbenone-treated stands have shown the significant reduction in MPB infestation without the accompanying source of attraction provided by

MPB baits? MPB dispersal may have been altered by the presence of pheromone baits, thereby affecting distribution among the other treatments. At this population level (3.7 infested trees per hectare in 1986), beetles from surrounding stands were probably drawn into the study blocks as indicated by the large increase in infested trees in 1987 (27.5 trees per hectare), especially in blocks containing MPB baits, which had 80.3 infested trees per hectare in 1987. How beetles would respond at higher population levels, or in the absence of the synthetic attractants, could not be deduced from the study. The investigators suggest that MPB may be attracted to the general area of verbenone-treated trees or stands and then infest trees where verbenone concentrations are low. Thus, while preventing infestation of treated trees and stands, infestation level of surrounding stands may be increased. Additional tests are under way to clarify this point.

OUTLOOK

The research results described here point to a growing understanding of the effects of semiochemicals, especially the antiaggregative components, on MPB host selection and aggregation behavior, and how they may best be integrated with existing suppression strategies once registered for operational use. Before these chemical messengers can be exploited to the fullest extent, it is likely several major gaps in our knowledge base regarding semiochemical deployment will need to be filled. These include (1) a knowledge of the structure of odor plumes and the effect topography and stand microenvironment have on their concentration and movement, (2) an understanding of the inherent differences in response between individual beetles in a population and between different population levels, (3) knowledge of the effects of environment on dispersion patterns of emerging adults, and (4) response of associated insects.

Even though this knowledge is lacking, test results obtained to date suggest that verbenone has the potential to prevent MPB infestations from reaching unacceptable levels in high-value lodgepole stands. Further, its potential for preventing rather than limiting the level of infestation would likely be enhanced if used in conjunction with synthetic MPB lures deployed to attract the beetle to traps or stands away from the area to be protected. At this point, test results suggest that verbenone has promise as an environmentally acceptable tool that can be incorporated with other strategies for preventing or suppressing MPB infestations, and therefore warrants the testing needed to determine how it can be deployed most effectively.

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MOUNTAIN PINE BEETLE POPULATION MANIPULATION STRATEGIES--PAST SUPPRESSION PRACTICES

Eugene D. Lessard

ABSTRACT: Suppression of mountain pine beetle is a viable strategy when implemented at the stand level in conjunction with ongoing vegetation management and is designed to protect a high value resource for a short period of time. There is a need to evaluate all management strategies for mountain pine beetle using an orderly process. Decision analysis is one such process that has demonstrated its utility in pest management.

Before I get into suppression, I would like to define a few terms. A mountain pine beetle EPIDEMIC occurs over an extensive area and consists of a matrix of INFESTATIONS at the stand level. At any one time in an epidemic, an infestation in a stand may be in the epidemic, increasing, outbreak or declining phase. Stands themselves have varying levels of susceptibility which contribute both to the probability of an infestation occurring and to the expected level of infestation. Not all stands become infested and participate in an epidemic. In fact, not all highly susceptible stands participate in a given epidemic.

The history of mountain pine beetle suppression is marked by strategies that were directed at an epidemic and were applied too late in the epidemic cycle at great expense in both dollars and man power. How often have we sent out the cry for action when massive amounts of tree mortality dotted the landscape? How often have we treated thousands of infested trees for three to five consecutive years only to see a general deline in populations in treated and untreated areas alike? How often have we viewed this decline and said "see, control works?" The reality of mountain pine beetle suppression is that we are very effective at what I call the "Visine treatment". We CAN get the red out. Other than "getting the red out" what have we accomplished with mountain pine beetle suppression programs? I'm afraid that most of our accomplishments have a negative connotation. We've convinced a large portion of the public, ourselves included, that suppression is a viable strategy over large expanses of forested acres. We've disrupted management plans and effectively delayed ongoing vegetation management that could have reduced stand susceptibility to infestation. We've neglected the resource management objectives of the land manager by implying that all infestations are "bad" and must be suppressed. A line in a song by Burt Reynolds best sums up our accomplishments. He sings "let's do something cheap and superficial". Superficial? No doubt! Cheap? Not in dollars and cents or manpower! Suppression costs have escalated from $1.50 per tree in the mid 1970's to $20.00 a tree in 1985. However, cheap in that we have effectively mitigated the land manager's and the public's concern - we got the red out! - without addressing the real and often controversial problem - and epidemic of mature trees.

Our accomplishments in insect suppression are akin to our accomplishments in fire suppression. We've had some real success in suppressing defoliator populations nationwide. The result has been an overall increase in the age of the forest, increase in offsite tree encroachment, increase in the progression of forest succession and, an increase in the overall susceptibility of the forest to insects and diseases. We've also had real success in suppressing fires in the past. By doing so we've increased the average age of the forest, increased offsite encroachment, increased the progression of succession and increased the overall susceptibility of the forest to all insects and diseases. Indirectly mountain pine beetle suppression has produced the same results by negatively impacting ongoing vegetation management. As a consequence, our ability to suppress insect epidemics and put fires out is declining rapidly even as our technology continues to advance.

There is a need to evaluate management strategies in an orderly process. By what process do you value the various alternative strategies? Using decision analysis, a procedure was developed to match management strategy to a land classification system (Freeling and Seaver 1980). The procedure first developed a land classification system based on the following criteria:

1. Stand risk to mountain pine beetle infestation
    a. moderate to high
    b. low
2. Land accessibility or operability
    a. accessible
    b. inaccessible

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Eugene D. Lessard is Group Leader, State & Private Forestry, Forest Service, U.S. Department of Agriculture, Anchorage, Alaska.

3. Tree value

a. high
b. low

From this eight land classifications were constructed, eg. moderate to high risk, accessible and, high value. The second part of this procedure involved the development of the following management strategies:

1. Thinning of stands

2. Preventive spraying

3. Favoring tree species other than the host species

4. Direct control actions taken to reduce the beetle population

5. No action

Using a range of current costs and values, each strategy was evaluated economically for each individual land classification. The viability of each strategy was then examined in the context of the land classification system and a preferred strategy developed. In addition, five major premises were developed during this process:

1. All host type, regardless of ownership can be stratified into land classification units.

2. Mountain pine beetle cannot be controlled by any method over extensive areas of land.

3. Management and control of mountain pine beetle is viable in restricted areas of type having relatively high value.

4. The ideal strategy for managing mountain pine beetle is to intensively manage the host type, thereby preventing outbreaks from occurring.

5. Prevention is a viable strategy only in moderate to high susceptible stands or in low susceptible condition in the near future. This thumb nail sketch of decision analysis is used here to demonstrate one strategy for managing mountain pine beetle in an orderly process. Not all strategies make sense under all conditions. The process can be made dynamic so that, as conditions change strategies can be reexamined and new preferred strategies developed. Gene Amman, Intermountain Research Station, is in the process of developing a decision model for mountain pine beetle. Once the framework of the model is developed, other bark beetle scenarios could be developed.

Is suppression ever a viable strategy for dealing with mountain pine beetle? The answer is clearly YES! Suppression makes sense when implemented at the stand level and designed to protect a valuable resource for a short period of time - 1 or 2 years. An example of a viable suppression strategy would be the use of preventive sprays with salvage logging in an infested campground to protect high value trees from immediate attack while preparing to implement a vegetation management plan to reduce overall stand susceptibility. Another example might be the use of pheromone baited trap stands or trees to reduce beetle pressure on high value sawlogs in an ongoing timber sale. The scenario seems clear. If we're going to attempt suppression it must be done at the stand level and in conjunction with ongoing vegetation management.

Knowing that suppression is ineffective over large forested areas, most entomologists realize the need to prevent infestations or, more realistically, to reduce the impact on the forest resource given an infestation will occur in the future. Forest Plans are delineating areas on the ground and addressing the management objectives for those areas. Management prescriptions are placing emphasis on particular resource needs for an area and outlying silvicultural practices to attain the stated objectives. Entomologists are providing input into the second round of the Forest decisions of the land manager.

Nationwide we have 56.6 million acres of host type susceptible to mountain pine beetle infestation. Annually, 4.3 million acres is at epidemic levels. At this rate all susceptible acres will be impacted over the next 13 years. However, not all of these acres will be negatively impacted. Forest plans must identify those acres that will be negatively impacted; strategies for reducing the impact; and, most important of all, the probable scenario if strategies are not implemented. Forest plans must also address the consequences of the "no action" alternative. This alternative too often implies that the vegetation will remain static over time.

The future is both positive and exciting. In the past few years entomologists and pathologists have taken the lead in developing the tools of silviculture as a means of attacking the cause and not the symptom of insect infestation. We have established long term studies to demonstrate the use of silviculture in pest management. Many of these demonstrations are just now yielding valuable information which should be documented in the forest planning process and implemented on the ground. We have entomologists and pathologists being trained and certified as silviculturists and accepted as knowledgeable specialists. We have a National Forest Health Initiative which has the stated objective of developing "a strategic plan to enhance and maintain the health of the Nation's forests which will be implemented through Forest Service programs and authorities." We have the opportunity to make a quantum leap in forest pest management. Let's not miss our chance.

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SEMIOCHEMICALS OF THE MOUNTAIN PINE BEETLE (*Dendroctonus ponderosae* Hopkins)

B. Staffan Lindgren and John H. Borden

ABSTRACT: Two decades of research on the chemical ecology of the mountain pine beetle has yielded four semiochemicals of real or potential value to forest managers. Aggregation of beetles to baited trees or artificial traps can be achieved with a mixture of *trans*-verbenol, *exo*-brevicomin and myrcene. Losses of lodgepole pine to mountain pine beetle were reduced significantly by the antiaggregation pheromone verbenone, even when challenged by attractive tree baits, in experiments in Idaho and British Columbia. New candidate semiochemicals have recently been identified and will be field tested in 1988 and 1989.

INTRODUCTION

Since the first discovery of the aggregation pheromone of *Ips paraconfusus* Lanier (Silverstein and others 1966), a multitude of semiochemicals have been identified from bark beetles in North America and Europe (Borden 1977, 1982). Extensive research has been conducted on the semiochemical complex of the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, over the last 20 years. In this paper we will present an overview of the most significant mountain pine beetle semiochemicals, and their role in the population dynamics of the mountain pine beetle and its insect associates.

Definition

Semiochemicals are naturally occurring compounds which are produced by an individual of a species and elicit a behavioral response in other individuals of the same or different species. Depending on the receiving and emitting species and whether the response is of benefit to the emitter or the receiver, a given semiochemical may be referred to as a pheromone, kairomone or allomone (Nordlund 1981). Other terms are recognized as well, but for this overview these three will suffice. Nordlund (1981) defined these terms as:

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B. Staffan Lindgren is Research Director, Phero Tech Inc., 1140 Clark Drive, Vancouver, B.C., Canada; John H. Borden is Professor, Centre for Pest Management, Department of Biolgical Sciences, Simon Fraser University, Burnaby, B.C., Canada.

- Pheromone: "a substance secreted by an organism to the outside that causes a specific reaction in a receiving organism of the same species."

- Kairomone: "a substance produced or acquired by an organism that, when it contacts an individual of another species in the natural context, evokes in the receiver a behavioral or physiological response that is adaptively favorable to the receiver but not to the emitter."

- Allomone: "a substance produced or acquired by an organism that, when it contacts an individual of another species in the natural context, evokes a response that is adaptively favorable to the emitter but not to the receiver."

As pointed out by Borden (1988a) these are functional designations, so that any given compound may have more than one function, e.g. a semiochemical could act as a pheromone intra-specifically and as a kairomone inter-specifically.

Pheromones may have different functions, e.g. they may be attractants or repellents. Bark beetle pheromones serve as aggregation pheromones, i.e. pheromones which attract members of both sexes, normally to a suitable breeding resource, and epideictic (antiaggregation) pheromones, which serve to prevent over-utilization of the same breeding resource.

THE ROLE OF SEMIOCHEMICALS IN MOUNTAIN PINE BEETLE POPULATION DYNAMICS

Semiochemicals influence mountain pine beetle population dynamics directly and indirectly. Borden (1988a) described five basic ways of action. Two of these affect mountain pine beetles directly as aggregation or antiaggregation pheromones, while the remaining three have indirect effects.

Direct Effects

Aggregation--Pioneer females identify susceptible trees by kairomonal, visual and/or gustatory cues. As the attack is initiated the combined effect of the female-produced aggregation pheromone *trans*-verbenol (Pitman and others 1968, 1969) and host kairomones, i.e. monoterpenes such as *alpha*-pinene (Pitman 1969)

or myrcene (Billings and others 1976; Borden and others 1983), attract other females and males to the tree. Males joining the attacking females release exo-brevicomin (Rudinsky and others 1974; Borden and others 1983; Conn and others 1983), which attracts mainly females.

Antiaggregation and Switching--As a tree becomes occupied by beetles establishing their brood galleries, increasing concentrations of exo-brevicomin and frontalin from males act as antiaggregation pheromones (Rudinsky and others 1974; Borden and others 1987) while decreasing concentrations of female-produced trans-verbenol and host volatiles reduce the attractiveness of the tree (Pitman and Vite 1969). In white pine stands, exo-brevicomin appears to serve as an antiaggregation pheromone even at concentrations which induce attraction in lodgepole pine stands (McKnight 1979). Furthermore, autoxidation and conversion by microorganisms of cis- and trans-verbenol to verbenone (Hunt and Borden 1988a; Hunt and others 1988) generate a strong anti-aggregation message, ensuring that overcrowding of the resource does not take place. Incoming females land away from the source of the anti-aggregation pheromones, thereby spreading the attack along the bole of the tree and eventually leading to the switching to adjacent trees, where the process is repeated (Geizler and Gara 1978; Berryman 1982).

Indirect Effects

Aggregation of Competing Species--Several bark beetle species are associated with mountain pine beetles (Amman 1975; Furniss and Carolin 1977). Although poorly documented, some species, e.g. Ips pini (Say), compete directly with the mountain pine beetle for breeding resources under some circumstances. Ips beetles may locate mountain pine beetle infested trees by kairomones produced by the beetles and/or the tree, and attack available portions of the trunk. Normally this would limit Ips-attacks to parts of the tree with thin phloem, but if the mountain pine beetle attack density is low Ips pini may attack the entire tree.

Inhibition of Aggregation by Competing Species--Mountain pine beetle males produce S-(+)-ipsdienol, which in parts of the range of Ips pini is antagonistic to the attractiveness of the aggregation pheromone R-(-)-ipsdienol (Hunt and others 1986). Mountain pine beetles also produce myrcenol, which has been shown to inhibit the response by Ips pini to traps baited with racemic ipsdienol (D. Miller[1], pers. comm.). It is likely that these compounds, which do not appear to affect mountain pine beetle aggregation, are produced to prevent competition for breeding resources by Ips pini (Hunt and others 1986).

Aggregation of Insect Associates--Predators, parasites and other insect associates of the mountain pine beetle may utilize the host and/or beetle produced kairomones to find a tree under attack (Borden 1988b). Such a tree may provide both food and breeding opportunities for some of these insects, e.g. the predatory clerid beetle Enoclerus sphegeus.

SEMIOCHEMICALS USED TO MANIPULATE POPULATIONS OF THE MOUNTAIN PINE BEETLE

A large number of compounds have been identified from the mountain pine beetle (table 1). Only a few of these have been found to have sufficient activity to warrant development for operational use.

trans-Verbenol is produced mainly by feeding females (Pitman and others 1968, 1969) and to a lesser extent by autoxidation of alpha-pinene (Hunt and others 1988). This aggregation pheromone is released after the female beetle starts boring into the tissues of the host tree, with maximum production occurring 12-18 hours after the female reaches the inner bark (Pitman and Vite 1969). When combined with host volatiles, trans-verbenol will induce attacks on baited trees, and it will attract limited numbers of mountain pine beetles to artificial traps or field olfactometers (Pitman 1971; Billings and others 1976; Conn and others 1983). trans-Verbenol is universally attractive in forests of white, ponderosa, and lodgepole pines (McKnight 1979).

exo-Brevicomin is mainly produced by feeding male mountain pine beetles (Pitman and others 1969). Its function is concentration-dependent (Rudinsky and others 1974; Borden and others 1987), and evidently varies with host species as well (McKnight 1979). In lodgepole pine forests exo-brevicomin enhances attacks on trees baited with trans-verbenol and a host volatile, and when released at low rates (0.05 mg/24 hrs) it improves catches of females in traps (McKnight 1979; Borden and others 1983; Conn and others 1983; Borden and others 1987). At higher release rates (0.5 and 5 mg/24 hrs) exo-brevicomin does not affect catches of females in traps, whereas male catches are reduced as compared to catches by trans-verbenol and myrcene. Ryker and Rudinsky (1982) reported that exo-brevicomin disrupted aggregation to trans-verbenol in Oregon, while Libbey and others (1985) could not establish any effect. In white pine stands in Idaho, McKnight (1979) found that exo-brevicomin disrupted aggregation to trees baited with trans-verbenol and alpha-pinene.

Myrcene is a relatively minor component of pine resin, but was found to be the best monoterpene synergist for trans-verbenol in ponderosa pine stands in Washington (Billings and others 1976) and in lodgepole pine stands in British Columbia

[1]Graduate Student, Centre for Pest Management, Department of Biological Sciences, Simon Fraser University, Burnaby, B.C., Canada.

Table 1--Semiochemicals isolated from the mountain pine beetle and/or tested in laboratory or field bioassays

Semiochemical	Activity	Selected References
trans-Verbenol	Attractive in traps and on trees when combined with a host volatile. (-)-Enantiomer active, antipode inactive.	Pitman and others 1968 McKnight 1979 Libbey and others 1985 Borden and others 1987
cis-Verbenol	Detected in trace quantities.	Pitman and others 1969
Verbenone	Detected in trace quantities in females. (-)-Enantiomer active in lodgepole pine. Mainly produced by autoxidation and microbial oxidation of alpha-pinene.	Pitman and others 1969 Ryker and Yandell 1983 Hunt and others 1988
exo-Brevicomin	Multifunctional pheromone. At low release rates synergizes trans-verbenol lodgepole pine. Inhibitory in white pine.	Pitman and others 1969 Rudinsky and others 1984 McKnight 1979 Borden and others 1987
endo-Brevicomin	Antiaggregation pheromone. No effect in lodgepole pine in British Columbia (unpublished data in Borden and others 1987).	Rudinsky and others 1974 Libbey and others 1985 Borden and others 1987
Frontalin	Multifunctional pheromone. Inhibitory at high release rates. Induces attacks on trees.	Ryker and Libbey 1982 Chatelain and Schenk 1984
Ipsdienol	S-(+)-ipsdienol produced by males. Inhibitory in trap bioassays.	Libbey and others 1985 Hunt and others 1986 Hunt and Borden 1988b
Acetone	In fresh resin of ponderosa pine. Inactive in trap bioassays.	Billings and others 1976 Libbey and others 1985
Ethanol	Inactive in field test. Arrestant in laboratory.	Libbey and others 1985 Syed and Graham 1987
Acetophenone	Attractive in laboratory bioassay. No effect in one field test.	Conn and others 1983
alpha-Pinene	Synergistic host volatile. Precursor of trans-verbenol.	Pitman 1971 McKnight 1979
beta-Pinene	Slightly synergistic with trans-verbenol on trees.	Borden and others 1983
Myrcene	Superior synergist in ponderosa and lodgepole pine.	Billings and others 1976 Borden and others 1983
beta-Phellandrene	Major monoterpene of lodgepole pine. Slightly synergistic in traps.	Conn and others 1983
3-Carene	Synergistic with trans-verbenol in traps and slightly so on trees.	Conn and others 1983 Borden and others 1983
Terpinolene	Synergistic with trans-verbenol in ponderosa pine, slightly so in lodgepole pine.	Billings and others 1976 Borden and others 1983
3-Caren-10-ol	Attracted more males in traps in B.C. and Oregon (contradiction between text and table in Libbey and others 1985).	Conn and others 1983 Libbey and others 1985

(con.)

Table 1--Continued

Semiochemical	Activity	Selected References
Myrcenol	Inhibitory tendency. Produced by males.	Conn and others 1983 Hunt and others 1986
2-para-Menthen-7-ol	Slightly synergistic with trans-verbenol and myrcene.	Conn and others 1983
trans-Pinocarveol	Isolated from fed beetles, but no apparent activity.	Libbey and others 1985
Pinocarvone	Reduced trap catches.	Libbey and others 1985
Borneol	Isolated from fed beetles.	Libbey and others 1985
Terpinen-4-ol	Isolated from fed beetles.	Libbey and others 1985
alpha-Terpineol	Isolated from fed beetles.	Libbey and others 1985
Myrtenol	Isolated from fed beetles.	Libbey and others 1985
Piperitone	Isolated from fed beetles, but no apparent activity.	Libbey and others 1985
Octanone	Isolated from fed beetles in sugar pine.	Libbey and others 1985
3,2-Methylcyclohexen-1-one	Isolated from beetles.	Rudinsky and others 1974
Diacetone-alcohol	Electrophysiological response.	Whitehead 1986
Camphene	Electrophysiological response.	Whitehead 1986
Limonene	Electrophysiological response.	Whitehead 1986
Bornyl acetate	Isolated from single beetles.	Gries and others 1988
4-Isopropylanisole	Isolated from single beetles.	Gries and others 1988

(Borden and others 1983; Conn and others 1983). Pitman (1971) originally identified alpha-pinene as the most attractive monoterpene in white pine stands in Idaho. McKnight (1979) found that (+)-alpha-pinene was the active enantiomer in white pine stands.

Verbenone was first identified as a trace compound in female mountain pine beetles (Pitman and others 1969). Hunt and others (1988) showed that verbenone is produced by autoxidation of trans- and cis-verbenol, and by oxidation of these compounds by yeasts associated with the beetles (Hunt and Borden 1988a). Ryker and Yandell (1983) showed that (-)-verbenone inhibits aggregation to attractive volatiles. When applied at a 10 x 10 meter grid in infested stands of lodgepole pine, verbenone reduced attacks even when challenged by attractive tree baits (Amman and others 1988; Lindgren and others 1988). However, verbenone did not totally prevent tree mortality in either of these studies.

CURRENT RESEARCH

Improved techniques for identifying candidate compounds from live individual, boring female beetles have been developed (Gries and others 1988), resulting in the identification of highly volatile compounds which may have a role in mediating the mass attacks on trees. Tests to assess the behavioral activity of these compounds will be conducted in 1988 and 1989.

CONCLUSIONS

The chemical ecology of the mountain pine beetle is complicated, involving a large number of semiochemicals stemming from the beetles themselves or from the host tree. In spite of two decades of research, it appears that the true nature of the semiochemical communication system of the mountain pine beetle has yet to be solved. Nevertheless, current knowledge has allowed development of tree baits consisting of trans-verbenol, exo-brevicomin and myrcene as an effective management tool in lodgepole pine stands (Borden and Lacey 1984; Borden 1988b) and

verbenone promises to be useful in some situations where high value stands need protection (Amman and others 1988; Lindgren and others 1988). If current research leads to a more powerful attractant, mass trapping may become a realistic tactic in the future.

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BAITING AND CUTTING TO MANAGE MOUNTAIN PINE BEETLE INFESTATIONS

Mark McGregor, Brian Steele, Patrick Shea, Wayne Bousfield

ABSTRACT: Semiochemicals have gained wide acceptance in the past 8 years. Operational projects have demonstrated that synthetically produced semiochemicals are an effective tool to augment management of mountain pine beetle in spot baiting, containment, and concentration of beetle populations. Analysis of data from baited and check stands in the Kootenai and Flathead National Forests (NF) shows baiting significantly changes the number of infested trees per acre. Tree diameter is statistically significant. The relative difference in infestation shows the 7-8.9 inch and 9+ inch DBH size classes incur larger changes in infestation rate than 5-6.9 inch DBH size classes. Habitat type group did not influence infestation rates in baited stands in the Kootenai NF but was statistically significant in the Flathead NF. Analysis of build-up ratios shows that baiting and habitat type group are statistically significant for stands in the Flathead NF, but only baiting, and not habitat type, affected build-up ratios in baited stands in the Kootenai NF. Mortality due to baiting depends on the percent of lodgepole pine in the 5-6.9 inch DBH classes in baited stands.

INTRODUCTION

The current cycle of mountain pine beetle (MPB) infestations in the western U.S. and provinces of Alberta and British Columbia began in the early 1970s (Van Sickle 1982; McGregor 1982). Epidemic infestations are present in lodgepole pine (LPP) forests of four western USDA Forest Service Regions and four of the six forest regions in the Province of British Columbia. The other two regions in British Columbia have some infestation (Hall 1985). Further, extensive areas of susceptible pine are at risk as MPB infestations continue to expand and new epicenters develop.

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Mark McGregor, Entomologist, PHERO TECH INC., Missoula, MT; Brian Steele, Statistical Consultant, Missoula, MT; Patrick Shea, Research Entomologist, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA; Wayne Bousfield, Entomologist, Timber Management, Northern Region, Forest Service, U.S. Department of Agriculture, Missoula, MT.

Various management approaches to reduce or prevent pine losses have been discussed by several other participants during this symposium. Strategies to reduce stand susceptibility by creating a mosaic of age and size classes and develop species diversity over several decades are most desired. Short-term strategies of totally suppressing a mountain pine beetle outbreak are unreasonable and probably impractical (Hall 1985), because stand conditions conducive for outbreak development would remain unchanged. Therefore, infestations would recur as soon as control strategies ceased. Also, it may be unrealistic to say direct control is entirely inappropriate or useless (Hall 1985). Direct control practices in specific areas can slow the rate of expansion of beetle populations and tree mortality. Slowing developing infestations in selected areas will buy time for developing management plans and implementing long-term strategies. This should be considered when developing harvesting and silvicultural prescriptions for specific areas. Indirect practices depend on modifying stand conditions that are conducive to beetle population build-up. Eventually, harvesting stands before they become susceptible and developing age-class and species mosaics should limit infestations and tree losses.

Whether implementing short- or long-term management strategies, the use of pheromones can enhance the efficiency of various management programs.

Pheromones, more specifically aggregation pheromones (semiochemicals), have been tested since the mid-1970s in British Columbia and the western U.S.

Early tests using <u>trans</u>-verbenol with <u>alpha</u>-pinene, and sometimes with ethanol included, showed that attractiveness of these combinations although positive was less than expected. When combined with single-tree treatment, such as preflight treatment with contact insecticides, postflight treatment with arsenicals, and preflight treatment of infested trees with penetrating insecticides for brood reduction, there was marked reduction in subsequent attacks when compared to check areas (Hall 1985). However, it was necessary to refine the pheromone complex before the use of semiochemicals could be considered for operational stand baiting.

RECENT TESTING

Following several years of field trials and testing of various combinations of potential synthetic chemicals by researchers at Simon Fraser University, notably Dr. John Borden, a consistently effective aggregation semiochemical was designed from a combination of trans-verbenol, exo-brevicomin, and myrcene (PMG/STRATFORD Project Ltd. 1983).

These formulations have been further field tested. By 1982, the use of tree bait semiochemicals was judged acceptable on an operational basis to enhance the effect of treatment (green stand harvest and sanitation cutting) in management of mountain pine beetle (Hall 1985).

A proven technique for tree-baiting with semiochemicals is to contain and concentrate infestations prior to logging (Borden and others 1983b). Originally developed for the Douglas-fir beetle, Dendroctonus pseudotsugae Hopkins (Pitman 1973), the technique was adopted for the mountain pine beetle. It is now used routinely as a prelogging treatment in high-hazard lodgepole pine stands in British Columbia (Borden and Lacey 1985).

Spot Baiting

Early detection of small spot infestations (up to 30 trees) and baiting two or more large-diameter trees should contain emerging beetle populations in the immediate vicinity (Borden and Lacey 1985). Following beetle flight, newly attacked trees can be removed by small sales, felled and burned, or felled and treated with chemicals. Direct control of developing small spot infestations can be expensive, but it can buy time until long-term management plans are implemented.

Grid Baiting

The tactic of baiting susceptible trees on a grid requires approximately two baits per acre. In smaller blocks or stands (up to 20 acres), baits are attached to large-diameter trees on a 50-meter grid, starting 25 meters in from the unit boundary. Beetles emerging from brood trees should be in close proximity to pheromone baits (Borden and others 1983a). Baits are applied prior to beetle flight and harvest of newly attacked trees or stands must be completed prior to beetle flight the following year.

Perimeter Baiting

The second method entails baiting trees 50 meters apart in two parallel lines, also 50 meters apart around the proposed block boundary (more than 20 acres). When groups of infested trees occur within the unit, grid baiting at 50 meters or closer, and baiting small infested groups, will further concentrate beetles within the cutting unit. Emerging beetles will be in close proximity to baits and the remaining population within the stand should either naturally find host trees or be contained by baits at the periphery of the stand. Both methods ensure that within stands either grid-baited or baited at the periphery, the dispersing beetles will fly into the attractant odor plume and respond upwind to a baited tree. This will result in mass attack and spillover into adjacent trees as the baited trees are mass attacked (Borden and others 1983a).

Tests in the Northern Region

Based on favorable results, by Borden and many others with management of mountain pine beetle, semiochemical baits were initiated in high-risk green and infested stands in the Northern Region of the USDA Forest Service (Montana and Northern Idaho) in 1984 and 1985. In 1984, approximately 7,090 MPB tree baits were applied at two/acre in lodgepole pine stands scheduled for logging in six National Forests (NF) and on Bureau of Indian Affairs (BIA) and Bureau of Land Management lands. Although baited and check stands were not surveyed systematically, general observations indicated baits worked well, particularly where beetle populations were not excessively high, and where susceptible trees remained for baiting and spillover.

In 1985, 6,950 tree baits were again applied at a rate of two/acre in 117 susceptible lodgepole pine stands in six National Forests and on BIA lands.

Stands baited in 1984 and 1985 were scheduled for harvest prior to beetle flight. Nearly all baited stands were logged prior to beetle flight both years. However, some were not logged due to sales being extended. Stands baited in 1984 that were not logged were rebaited in 1985. Stands baited in 1985 but not logged prior to beetle flight in 1986 were not rebaited because the Environmental Protection Agency stopped the use of tree baits.

During the 1985 season, data were collected from 71 baited stands and 29 check stands. Stands were surveyed, using 10 BAF Prism plots, and all trees 5 inches DBH and larger and tree mortality cause by year were recorded. It was not possible to survey all 117 stands baited in 1985 since many were logged soon following beetle flight.

The data are observations based upon number of beetle-infested trees per acre by DBH size classes (5-6.9 inches, 7-8.9 inches, and 9+ inches), in baited and check stands. Several measures of beetle infestation were used, depending on objectives of the analysis: (1) change in number of infested trees per acre by DBH size class and habitat type from pre- to posttreatment, (2) build-up ratio of infested trees pre- to posttreatment, and (3) percent lodgepole pine mortality as affected by

percentage of trees in the 6-7.9 inch DBH size classes prebaiting.

The change in number of infested trees per acre from pre- to posttreatment was computed as post-treatment infested trees per acre minus pre-treatment infested trees per acre. The build-up ratio was computed as infested trees/acre post-treatment divided by infested trees/acre pre-treatment. Two other variables used in this analysis are percent susceptible LPP in the 5-6.9 inch DBH class, and percent mortality. Percent LPP in the 5-6.9 inch DBH class was computed as the number of LPP in the 5-6.9 inch DBH class at the pretreatment measurement date, divided by the total number of susceptible LPP in the stand. Percent mortality was computed as the total number of LPP killed by beetles following baiting, divided by the total number of LPP > 5 inches DBH in the stand.

Methods

The primary statistical procedure used in this analysis is the ANOVA (analysis of variance). In addition, Scheffe's multiple comparison test was used to determine the sources of variation in terms of specific treatment combinations (Snedecor and Cochran 1980, p. 232). Scheffe's test was carried out by computing a two-sample "t" statistic and comparing the value to the critical "t" specified by the test. Unfortunately, Scheffe's test has little power when sample sizes are small, but it does provide a method of separating very large differences from the merely large differences. For this reason, the primary use of Scheffe's test in this analysis was to rank differences between treatment combinations, and not as a formal test.

The computed value of a test statistic is noted as statistically significant if the p value associated with the statistic is less than 0.05.

Distribution of Samples and General Trends

Table 1 displays by habitat type group the number of stands sampled on the Kootenai NF. Sample sizes were restrictively small for most habitat type groups. Table 2 displays stands surveyed by habitat type group for the Flathead NF. This sample was quite small for comparative purposes.

Two habitat type groups in each National Forest have enough representation for formal analysis. For the Kootenai NF, the first habitat type group is the warm-wet (w-w) habitat type group consisting of habitat types 290, 420, 470, 520, 530, 591, 592, and 571. The second habitat type group is the cool-wet (c-w) habitat type group consisting of habitat types 620, 660, 663, 670, and 740.

Table 1--Number of observations for baited check stands by habitat type group, Kootenai NF, Montana, 1985

Habitat Type Group Number	ADP code	Name	Number of Stands Check	Baited
1	250	Psme/Vaca	0	1
1	260	Psme/Phma	0	1
1	262	Psme/Phma	0	1
2	290	Psme/Libo	1	2
2	420	Pice/Clun	0	2
2	470	Pice/Libo	0	1
2	520	Abgr/Clun	0	1
2	530	Thpl/Clun	0	1
2	591	Abgr/Libo-Libo	1	1
2	592	Abgr/Libo-Xete	1	0
2	571	Tshe/Clun	1	0
3	620	Abla/Clun	0	2
3	660	Abla/Libo	0	7
3	663	Abla/Libo-Vasc	1	0
3	670	Abla/Mefe	1	9
3	740	Abla/Alsi	1	0
4	650	Abla/Caca	0	1
5	690	Abla/Xete	1	5
5	720	Abla/Vagl	0	1
6	730	Abla/Vasc	0	2

Table 2--Number of observations for baited and check stands by habitat type group, Flathead NF, Montana, 1985

Habitat Type Group Number	ADP Code	Name	Number of Stands Check	Baited
1	750	Abla/Caru	0	1
1	280	Psme/Vagl	0	1
1	290	Psme/Libo	0	1
1	730	Abla/Vasc	0	1
2	620	Abla/Clun	0	2
2	621	Abla/Clun-Clun	1	1
2	624	Abla/Clun-Xete	1	1
2	625	Abla/Clun-Mefe	4	4
2	660	Abla/Libo	3	1
2	662	Abla/Libo-Mefe	3	1
2	670	Abla/Mefe	0	2
3	640	Abla/Vaca	1	2
3	663	Abla/Libo-Vasc	0	1
3	690	Abla/Xete	1	5
3	692	Abla/Xete-Vasc	6	7
4	654	Abla/Caca	0	1
5	312	Psme/Syal	1	0

Table 3--Factors affecting infestation rates, and their levels.

Factor	Levels 1	2	3
Treatment	baited stands	check stands	
DBH class (in.)	5 - 6.9	7 - 8.9	9+
HT group (Flathead NF)	cool-wet	cool-dry	
HT group (Kootenai NF)	warm-wet	cool-wet	

In the Flathead NF, the cool-wet (c-w) habitat type group consists of habitat types 620, 621, 624, 625, 660, 662, and 670. The cool-dry (c-d) habitat type group consists of habitat types 640, 663, 690, and 692.

Factors used in the analysis are displayed in table 3.

To obtain a general picture of the distribution of the data, pretreatment infestation (trees per acre) was plotted versus posttreatment infestation (trees per acre). Figure 1 displays infested trees/acre from pre- to postbaiting and pre- to post-flight for check stands for the Flathead NF, and figure 2 displays infested trees/acre from pre- to postbaiting and pre- to postflight for check stands for the Kootenai NF.

There is clearly a significant increase in infestation for both baited and check stands in both forests. Also, the relative lack of check stands is apparent. Observations made in the Flathead NF are substantially larger on the average, in both pre- and posttreatment conditions, than in the Kootenai NF.

Determination of Differences in Infested Trees Per Acre

This analysis attempts to determine the sources of variation in change in infested trees per acre from pre- to posttreatment.

Kootenai NF--Table 4 presents the ANOVA table for the three-way analysis of variance.

Treatment is a statistically significant factor in explaining the variation in change in infested trees per acre from pre- to posttreatment. The average increase in infestation rate for baited stands is 37.1 trees per acre, and 7.8 trees/acre for check stands. DBH is also statistically significant, and the relative differences in infestation rates show that the 7-8.9 inch and 9+ inch DBH classes incur larger changes in infestation rate than the 5-6.9 inch DBH class.

Habitat type group was not found to be a significant factor in explaining changes in infestation rates. The fraction of unexplained variation (50619.93) relative to the total variation (81028.52) is fairly large. This indicates that while treatment and DBH class explain a significant amount of the variation, there is still a large variation unexplained.

Changes in Infestation Rate by DBH Class and Treatment

Table 5 shows specific differences between baited and check stands in change in infested trees per acre within each DBH class. Significance at the 0.05 level was tested by Scheffe's test.

Results of the two sample t-tests show that there are very large differences in infestation rate change associated with treatment in the 7-8.9 inch and 9+ inch DBH classes. Data are insufficient to provide strong evidence of differences between treatments in the 5-6.9 inch DBH class.

Flathead NF--Table 6 presents the ANOVA table for the three-way analysis of variance.

Treatment is a statistically significant factor in explaining variation in the change in infestation rate from pre- to posttreatment. The average change in infestation rate for baited stands is 52.9 trees per acre, and 23.1 trees/acre for check stands. Also, DBH and habitat type are statistically significant. The average change in infestation rate is greater in the cool-dry habitat type group (56.0 trees per acre) compared to the cool-wet habitat type group (26.5 trees per acre). As in the analysis of the Kootenai NF data, there was a substantial amount of unexplained variation.

Changes in Infestation Rate by DBH Class, Habitat Type Group, and Treatment

Table 7 shows specific differences between baited and check stands in change in infested trees per acre within each level of DBH class and habitat type group.

No treatment differences were found to meet the critical t for Scheffe's test. This is attributed to the small degrees of freedom available for the tests, the large amount of unexplained variation, and the conservative nature of Scheffe's test. There is some evidence of a consistent trend relating DBH class and the difference between baited and check stands. Both tables 5 and 7 show the difference between check and baited stands to be smaller in the 5-6.9 inch DBH class than the 7-8.9 inch DBH and 9+ inch DBH classes, except in the c-d habitat type group (Flathead NF), 9+ inch DBH class. This number may be small due to a large portion of the trees in the 9+ inch DBH class having been attacked before baiting, and because the 5-6.9 inch DBH classes are not as susceptible as

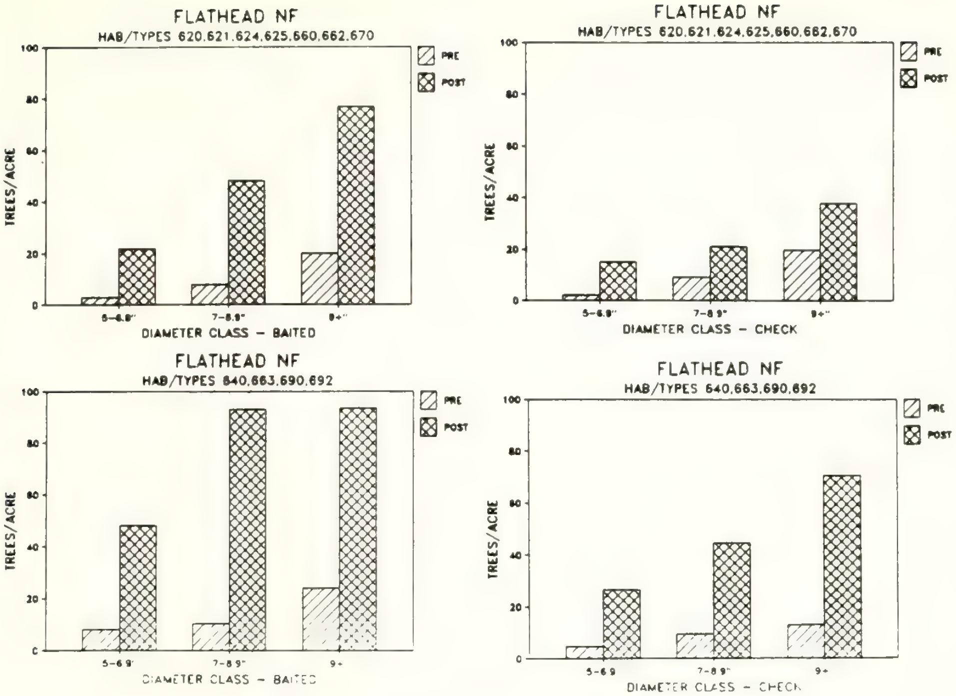

Figure 1--Trees killed per acre by diameter class from pre- to post-baiting, and pre- to postbeetle flight in check stands, Flathead National Forest, Montana, 1985

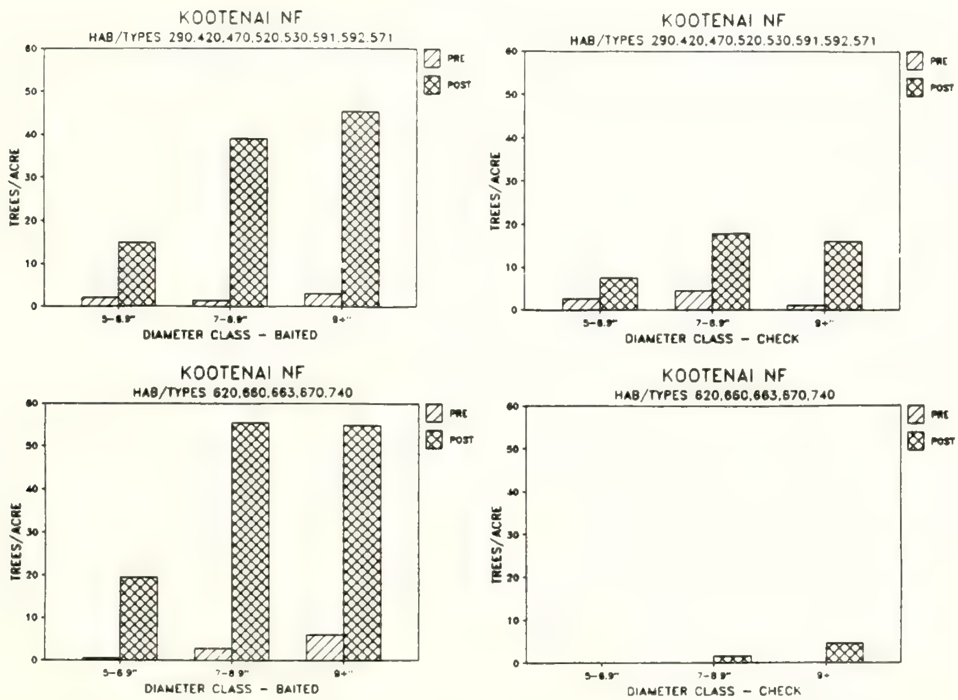

Figure 2--Trees killed per acre by diameter class from pre-to post-baiting, and pre- to postbeetle flight in check stands, Kootenai National Forest, Montana, 1985

Table 4--Analysis of variance table--Kootenai NF, Montana, 1985

Source of Variation	DF	Sums of Squares	Mean Square	F-ratio	P-value
Mean	1	81028.52			
Treatment	1	14811.09	14811.09	28.674	0.000
DBH	2	14902.74	7451.37	14.426	0.000
HT group	1	694.75	694.75	1.345	0.265
Error	98	50619.93	516.53		

Table 5--Average change in infestation rate from pre- to posttreatment within each DBH class on the Kootenai NF, Montana, 1985

DBH class	Infested Trees/Acre Baited	Infested Trees/Acre Checks	Difference	DF	Significance at 0.05 level
5 - 6 in.	16.98	2.37	14.62	31	ns
7 - 8 in.	47.65	8.92	38.72	33	s
9 + in.	46.79	10.97	35.81	33	s

Table 6--Analysis of variance table--Flathead NF, Montana, 1985

Source of Variation	DF	Sums of Squares	Mean Square	F-ratio	P-value
Mean	1	223894.03			
Treatment	1	29548.59	29548.59	24.983	0.000
DBH	2	17793.82	8896.91	7.522	0.001
HT group	1	20431.86	20431.86	17.275	0.000
Error	132	156119.77	1182.72		

Table 7--Average change in pre- to posttreatment infestation rate within each DBH class on the Flathead NF, Montana, 1985

HT group	DBH	Infested Trees/Acre Baited	Infested Trees/Acre Checks	Difference	DF	Significance at 0.05 level
c-w	5 - 6.9 in.	18.69	12.95	5.74	22	ns
c-w	7 - 8.9 in.	40.45	11.99	28.47	22	ns
c-w	9 + in.	56.77	18.16	38.62	22	ns
c-d	5 - 6.9 in.	40.16	21.66	18.55	20	ns
c-d	7 - 8.9 in.	82.66	35.30	47.36	20	ns
c-d	9 + in.	69.33	57.47	11.86	20	ns

larger diameter classes (Cole and Amman 1969; Cole and others 1976; Klein and others 1978; Rasmussen 1972).

Examination of the sample means, displayed in tables 5 and 7, also suggests that DBH class is a major determinant of infestation rate (larger DBH classes suffer larger increases in infestation rates irrespective of treatment).

Conclusions

There is strong evidence that treatment was a factor in determining the change in infested trees per acre, and that the effect of baiting substantially increases the number of infested trees per acre. The fact that differences between specific treatment combinations are not statistically significant can be attributed to the small sample sizes available for these multiple comparison tests, and the amount of unaccounted for variation. There is a clear pattern of larger changes in infested trees per acre in the larger DBH classes. Further, it appears that the effect of baiting is greater in the larger DBH classes. Habitat type group is not a consistent factor in explaining variation in the change in infested trees per acre. However, a larger sample of habitat type groups probably would reduce variation.

Determination of Differences in Build-up Ratio

This analysis attempts to determine sources of variation in the build-up ratio. One drawback to the use of ratios is that a ratio cannot be computed if the denominator of the ratio has a zero value. In these data, there are numerous stands in which the pretreatment infestation rate is 0.0, particularly for the Kootenai NF. These stands are omitted in the following analysis. The distribution of sample observations is displayed in table 8.

The use of build-up ratios instead of the pre- to posttreatment change as a measure of infestation trend has the effect of reducing the relative importance of the stands in which pretreatment infestation was high. For example, consider two stands with pretreatment infestation rates of 10 and 50 trees per acre. Suppose infestation in both stands increases by 50 trees per acre. The change in infestation rates (pre- to posttreatments) is 50.0 in both stands; however, the build-up ratios are 5.0 and 1.0 for each stand, respectively. Consequently, ANOVA using the build-up ratio is more sensitive in detecting factors that affect stands with low initial infestation rates, compared to factors that affect stands with high initial infestation rates.

Kootenai NF--Variation in build-up ratio is shown in table 9. The sensitivity of this analysis is reduced relative to the previous analysis of the Kootenai NF data (using the change in infested trees per acre) because of the reduction of sample size from 103 to 46 observations.

Treatment is the only statistically significant factor. The mean build-up ratio for check stands is 2.6, compared to 14.0 for baited stands. The data are insufficient to conclude that there are substantial differences in the build-up ratio between different DBH classes. This result, contradicting the previous results using the change in infestation rate, may be attributable to sample size differences. The fraction of variation that remains unexplained is large relative to the total variation.

Changes in Build-up Ratio by DBH Class and Treatment

Table 10 shows specific differences between baited and check stands within each DBH class for the Kootenai NF data. Significance tests are not computed since the analysis of variance did not find DBH to have a statistically significant effect upon build-up ratio. The trend of DBH and build-up ratio is not inconsistent with previous results.

Flathead NF--Variation in build-up ratio is described by table 11. Both treatment and habitat type group are statistically significant. The mean build-up ratio for check stands is 4.9, compared to 8.9 for baited stands. DBH was not a significant factor in determining build-up ratio. Unexplained variation is again a substantial fraction of the total variation.

Specific differences between baited and check stands are not identified as statistically significant.

Changes in Build-up Ratio by Habitat Type Group and Treatment

Table 12 shows differences between baited and check stands within each habitat type group for the Flathead NF data.

Changes in Build-up Ratio by DBH Class and Treatment

Table 13 displays the trends in build-up ratio by DBH class for the Flathead NF.

Tables 10 and 13 show that the 7-8.9 inch DBH class is observed to have the largest difference in build-up ratio among the three diameter classes.

Table 8--Number of valid observations based upon build-up ratio

Flathead NF		Baited Stands			Check Stands		
		DBH Class			DBH Class		
		5 - 6.9	7 - 8.9	9 +	5 - 6.9	7 - 8.9	9 +
HT	c - w	7	9	12	3	9	10
group	c - d	9	14	15	4	7	8

Kootenai NF		Baited Stands			Check Stands		
		DBH Class			DBH Class		
		5 - 6.9	7 - 8.9	9 +	5 - 6.9	7 - 8.9	9 +
HT	w - w	3	4	6	1	3	3
group	c - w	2	10	15	0	0	0

Table 9--Analysis of variance table for build-up ratio--
Kootenai NF, Montana, 1985

Source of Variation	DF	Sums of Squares	Mean Square	F-ratio	P-value
Mean	1	7513.74			
Treatment	1	788.40	788.40	5.292	0.026
DBH	2	591.50	295.75	1.985	0.150
HT group	1	26.23	26.23	0.176	0.677
Error	41	6107.61	148.97		

Table 10--Mean build-up ratio for each DBH class on the
Kootenai NF, Montana, 1985

DBH class	Baited Stands Trees/Acre	Check Stands Trees/Acre	Difference
5 - 6 in.	4.34	0.54	3.80
7 - 8 in.	18.40	1.27	17.13
9 + in.	13.52	6.54	6.97

Table 11--Analysis of variance table for build-up ratio--
Flathead NF, Montana, 1985

Source of Variation	DF	Sums of Squares	Mean Square	F-ratio	P-value
Mean	1	7028.40			
Treatment	1	347.62	347.62	5.602	0.020
DBH	2	175.63	87.82	1.415	0.248
HT group	1	299.73	299.73	4.830	0.030
Error	100	6205.37	62.05		

Table 12--Differences between treatments in the mean build-up ratio within habitat type groups--Flathead NF, Montana, 1985

HT group	Baited Stands Trees/Acre	Check Stands Trees/Acre	Difference	DF	Significance at 0.05 level
c-w	7.32	2.86	4.46	57	ns
c-d	10.00	7.40	2.60	54	ns

Table 13--Mean build-up ratio for each DBH class on the Flathead NF, Montana, 1985

DBH class	Baited Stands Trees/Acre	Check Stands Trees/Acre	Difference
5 - 6.9 in.	18.77	5.57	3.20
7 - 8.9 in.	11.84	4.29	7.55
9 + in.	6.38	5.29	1.09

Conclusions

The analysis shows baiting substantially increased the number of infested trees per acre. Differences between specific treatment combinations were not found to be statistically significant using Scheffe's test. Using the build-up ratio as a response variable apparently has the effect of reducing the influence of stands with large pretreatment infestation rates since these stands cannot experience very large build-up rates. It is suggested that high pretreatment infestation rates have reduced the difference in build-up ratios between the 7-8.9 inch and 9+ inch DBH classes, and the 5-6.9 inch DBH class.

Effect of LPP in the 5-6.9 inch DBH Class

This analysis attempts to determine whether the effectiveness of baiting is affected by the percentage of LPP in the 5-6.9 inch DBH class. Field observations suggest that stand composition is a major factor in determining the effectiveness of baiting. Specifically, the percentage of lodgepole pine in the 5-6.9 inch DBH class is thought to affect infestation and response to baiting. The objective of this analysis is to determine if the percentage of lodgepole pine in the 5-6.9 inch DBH class influences the effectiveness of baits.

In this analysis, the percent LPP in the 5-6.9 inch DBH class is compared to the percent of total LPP mortality (all DBH classes). All stands are used in this analysis instead of restricting the analysis to the major habitat type groups since the intent is not to determine the effect of specific factors, but to determine a general trend applicable to all stands in a National Forest.

Figures 3 and 4 are plots of percent LPP in the 5-6.9 inch DBH class versus percent mortality. A regression equation is graphed on each figure, summarizing the trend in baited and check stands in the Flathead NF, but only baited stands in the Kootenai NF. The regression equations are computed by regressing percent LPP mortality on percent LPP in the 5-6.9 inch DBH class. The appendix provides the statistics for the regression equations.

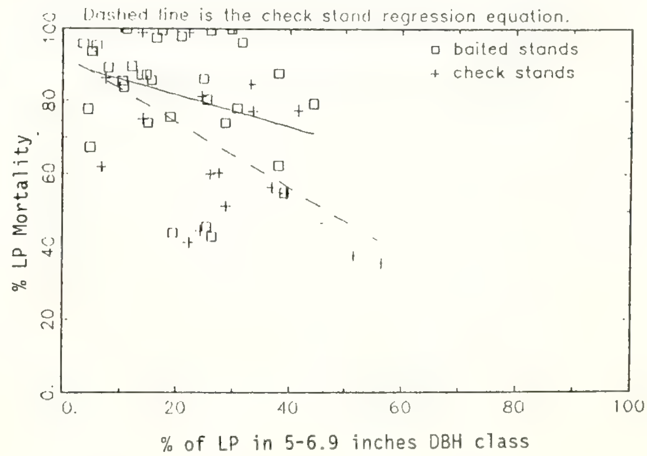

Figure 3--Plot of percent of LP in the 5-6.9 inch DBH class versus percent LP mortality observed at remeasurement, and the graph of the regression equations. Flathead National Forest, Montana, 1985

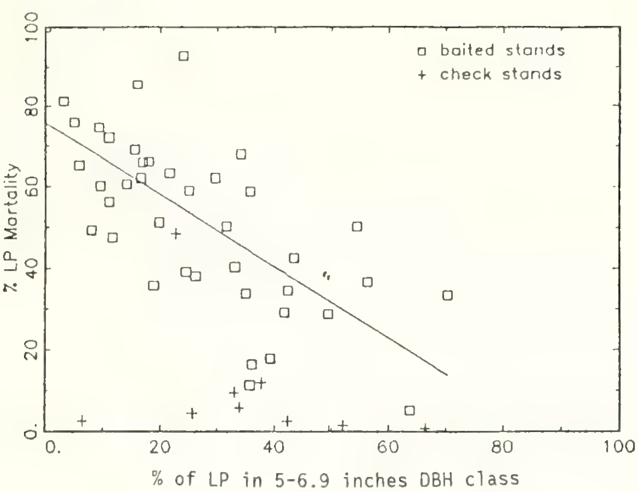

Figure 4--Plot of percent of LP in the 5-6.9 inch DBH class versus percent of LP mortality observed at remeasurement, and the graph of the regression using baited stands. Kootenai National Forest, Montana, 1985

Results--Flathead NF

Figure 3 shows the plotted data and the fitted regression equation for the Flathead NF. The range of the data is unfortunately small as there were no baited stands with more than 44 percent of the pretreatment LPP in the 5-6.9 inch DBH class. Data show that stands with small percent LPP in the 5-6.9 inch DBH class suffer higher mortality rates. The mortality rate declines as the percent LPP in the 5-6.9 inch DBH class increases. The mortality rate is still quite high at the largest observed percent LPP in the 5-6.9 inch DBH class. The regression analysis in the Appendix shows that percent LPP in the 5-6.9 inch DBH class is not a statistically significant predictor of percent LPP mortality since the t statistic testing the significance of the independent variable is 1.663 and the associated p value is 0.107.

Percent LPP in the 5-6.9 inch DBH class is a statistically significant (p value = 0.001, Table 3 Appendix) predictor of LPP mortality in the check stands. However, the relationship is not strong because of the low r2 (0.435). For check stands, as percent LPP in the 5-6.9 inch DBH class increased, average DBH declines, thus decreasing overall stand susceptibility (Cole and Amman 1969; Cole and others 1976; Klein and others 1978).

Results--Kootenai NF

Figure 4 shows the plotted data and the fitted regression equation for the Kootenai NF. The range of susceptible LPP in the 5-6.9 inch DBH class is 0 to 70 percent; a substantial difference compared to data from the Flathead NF. Data show a clear tendency for the mortality rate to decline as the percentage of the LPP in the 5-6.9 inch DBH class increases. The regression analysis in the Appendix shows that percent LPP in the 5-6.9 inch DBH class is a statistically significant predictor of percent LPP mortality since the t statistic testing the significance of the independent variable is 16.109 and the associated p value is 0.000.

Conclusions

Data from baited stands in the Kootenai NF show percent mortality due to baiting does depend upon percent LPP in the 5-6.9 inch DBH class, and the effect is to retard posttreatment mortality. The data are insufficient to support this conclusion for the Flathead NF. A possible reason is that the range of the data is limited and beetle infestation in the vicinity of Flathead NF stands was so great that the beetles attacked the majority of trees larger than 5 inches DBH prior to baiting. Data from baited stands in the Kootenai NF and check stands in the Flathead NF suggest a strong preference for larger DBH classes.

Figure 4 can be used to establish a maximum percent LPP in the 5-6.9 inch DBH class such that baiting is effective. For example, to obtain at least 50 percent mortality following baiting requires that no more than 29 percent of the LPP is in the 5-6.9 inch DBH class. On the other hand, if 60 percent of the LPP is in the 5-6.9 inch DBH class, then only 23 percent mortality is expected after baiting. Caution ought to be exercised in the use of the regression equations in figures 3 and 4 since LPP diameter distribution in stands of other forests are likely to be different.

One can rest assured that semiochemical baiting and sanitation logging will not remove all infested trees in localized areas. Many instances can be brought to mind that following cutting and removing infested trees, one later finds individual attacked trees or small patches of infested trees around the periphery of cut blocks. Whether these beetles come from brood trees not included in the cut block or from a population remaining in stumps following cutting is not really important. What does matter is that these newly infested trees or groups of trees do represent the potential for building beetle populations in the surrounding stands and should be dealt with if the stand is in a beetle management area. Where infested trees are detected late in the year following cutting, baits can be placed around the block during spring or early summer the following year. Baits should be attached to large-diameter trees, 25 meters in from the edge, and if the cut unit boundary is more than a spot, baits can be spaced at 100-meter intervals around the edge. Baited trees will serve as aggregation centers for the residual beetle population; following flight, newly attacked trees can be harvested with small sales, felled and burned, or treated with chemicals (Borden and others 1983b; Hall 1985).

Diversion Baiting

Baiting to divert beetles away from leave strips (riparian areas or other high-value stands) may be an additional option (Borden and Lacey 1985); however, this strategy has not been tested to our knowledge. It is possible to use it in conjunction with antiaggregation pheromones (verbenone) and possibly repellents, but field testing of this strategy is needed prior to it being recommended for operational use. Baiting stands scheduled for harvest adjacent to or near stands protected by use of ground or aerially applied antiaggregates or repellents may prove to be a useful tool.

It must be emphasized that semiochemicals will not control beetle populations. They may in fact aggravate the problem. Aggregation pheromones manipulate beetle populations by restricting dispersal, or may possibly enhance it in the case of antiaggregates or repellents. If not used in conjunction with harvesting or single-tree treatment, the infestation will probably expand more than if pheromones were not used. Where semiochemical tree baits are used, beetles normally lost during dispersal may have a better chance of finding suitable host trees, thereby increasing the number of trees successfully attacked over the number of trees attacked had baits not been used (Hall 1985). Careful selection and baiting of larger diameter trees, which the beetle naturally prefers, will increase effectiveness of baiting and probability of mass attack. Baits should be placed in the field well ahead of any beetle flight that might result in establishment of natural competing attraction centers. It is unlikely that any semiochemical tree bait will compete or outcompete a natural attractant.

Semiochemical tree baits are past the stage of just being a scientific curiosity. However, it should be kept in mind that pheromones, whether attractants, antiaggregates, or repellents, must be used in coordination with other appropriate management strategies.

We are all involved in management programs to reduce or avoid losses to bark beetles. We should employ those strategies that reduce the long-term impacts of bark beetles through harvesting or other short-term methods. Semiochemicals should be incorporated into our "bag of tricks" to help meet these management objectives.

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Appendix. Regression Equations Shown in Figures 3 and 4.

A regression equation is fit to the data in figure 3 to summarize the expected percent mortality given the percent susceptible LP in the 5-6 inch DBH class. The regression model specifies that the dependent variable is percent mortality, and the independent variable is percent susceptible LPP in the 5-6 inch DBH class. The regression statistics are displayed in table 14.

The same regression equation is fit to the data in figure 4 from the Kootenai NF. The regression statistics are displayed in table 15.

Table 14--Statistics for the regression of percent LPP mortality on percent susceptible LPP in the 5-6 inch DBH class using baited stands on the Flathead National Forest, Montana

Observations:	32	Degrees of freedom:	30
R-squared :	0.084		
Residual SS :	7830.292	Std error of est :	16.156
Total SS :	8552.402	F(2 ,30)=2.7666	P-value=0.08

Variable	Coeff.	Std. Error	t-Stat	P-Value
CONSTANT	90.154	5.838	15.441	0.000
% LPP 5-6	-0.428	0.257	-1.6633	0.107

Table 15--Statistics for the regression of percent LPP mortality on percent susceptible LPP in the 5-6 inch DBH class using baited stands on the Kootenai National Forest, Montana

Observations:	40	Degrees of freedom:	38
R-squared :	0.479		
Residual SS :	9664.144	Std error of est :	15.947
Total SS :	18562.058	F(2 ,38)=34.9871	P-value=0.00

Variable	Coeff.	Std. Error	t-Stat	P-Value
CONSTANT	75.653	4.696	16.109	0.000
% LP 5-6	-0.882	0.149	-5.915	0.000

Table 16--Statistics for the regression of percent LPP mortality on percent LPP in the 5-6.9 inch DBH class using check stands on the Flathead National Forest, Montana

Observations:	21	Degrees of freedom:	19
R-squared :	0.435		
Residual SS :	5239.637	Std error of est :	16.606
Total SS :	9266.386	F(2, 19)=14.6081	P-value=0.00

Variable	Coeff.	Std. Error	t-Stat	P-Value
CONSTANT	92.204	6.811	13.538	0.000
% LP 5-6	-0.898	0.236	-3.821	0.001

THE USE OF MOUNTAIN PINE BEETLE AGGREGATION SEMIO-CHEMICALS IN BRITISH COLUMBIA

P.M. Hall

ABSTRACT: The Province of British Columbia has been experiencing outbreaks of mountain pine beetle since the mid-1970's. In response, an aggressive management program was initiated in 1984 to reduce the rate of loss, protect high value stands, and allow an orderly, co-ordinated approach to lodgepole pine/mountain pine beetle management. This program has included extensive use of aggregating semio-chemical baits as an integral part of many activities. These baits have proven effective in manipulating localized populations of beetles, thereby enhancing the effectiveness of management efforts.

INTRODUCTION:

Now and for the foreseeable future, the forest industry is the number one economic driving force in British Columbia. In 1985, forest-based industries directly employed about 7 per cent of British Columbia's work force and formed the economic base for many communities on the coast and in the interior of the Province. The value of shipments from British Columbia wood industries was about $5.1 billion that year, and was an additional $3.4 billion from paper and allied industries. These accounted for about 45 per cent of the total value of shipments from British Columbia's manufacturing industries.

It is the mandate of the government to support this industry and ensure a continuing, strong economy. Large scale depletions of merchantable timber can cause significant disruptions to the industry and may lead to closures of specific processing facilities in affected areas. The government, through the policies and activities of the Ministry of Forests and Lands, has a responsibility to deal with potential depletions as occur in large outbreaks of bark beetles. Damage and losses must be minimized if at all possible.

In the interior of British Columbia, the forest industry is heavily dependent on a diet of lodgepole pine, Pinus contorta, (Anon, 1984 and 1986). The volume of pine harvested in the province in 1985/86 was 18.2 million m^3, second only to the volume of spruce harvested. The area occupied by mature pine types represents about 21 per cent (8.1 million hectares) of the total Forest Land Base in Timber Supply Areas (TSA's); the volume of mature pine types represents about 24 per cent of all mature volume in TSA's and 20 per cent of all volume of mature and immature combined. TSA's represent approximately 92% of the forest land base of the Province; the remainder is managed under other tenure agreements. From these figures it is obvious that British Columbia is "blessed" with vast amounts of pine with an age-class imbalance biased towards mature types. In many respects, we have an infestation of lodgepole pine highly susceptible to mountain pine beetle, Dendroctonus ponderosae. These statistics are presented to emphasize the need to put management of mountain pine beetle in the context of general forest management objectives. Catastrophes such as widespread mountain pine beetle outbreaks affect many aspects of management.

Mountain pine beetle arrived on this stage most recently in the early 1970's. By the mid-1970's infestations were noted at many locations throughout the interior of the Province. Although salvage logging was directed at infested stands in most of these areas, little was done to try to reduce the active beetle populations.

Throughout the 1970's, mountain pine beetle expanded, both in the size of particular infestations and in the number of infestations. It was projected that the eventual size of the outbreak in the Province would be limited primarily by the availability of host.

In 1981, active infestations covered over 158,000 ha (Fiddick and VanSickle, 1982) and had killed a volume estimated at 6.6 million m^3 in the preceding year alone. By 1983, infestations covered over 460,000 ha and in 1984 had reached over 480,000 ha (Wood and others, 1985). Total cumulative losses to that time were estimated as over 50 million m^3 of pine.

The impacts of these outbreaks affected management plans at all levels. Large areas of gray, dead stands of pine existed in many locations in the Province. Many of these stands had previously been included in the net operable forest land base and therefore the volumes were

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P.M. Hall, Forest Entomologist, British Columbia Ministry of Forests and Lands, Protection Branch, Victoria, B.C., Canada.

included in determinations of cut levels. These gray stands were declining in value rapidly and affected Regions were anticipating reductions to annual allowable cuts (AAC) at least in the short-term (20 years) due to age class gaps in the timber profile. Many accommodations had to be made: development plans and access construction schedules were altered; AAC's were reviewed and modified; plans and costs of rehabilitation were developed; and, the short and long-term probabilities of fire were considered when developing protection plans.

Some sort of program was required to be put in place. Rather than address a specific outbreak, a program was developed that would allow action to be taken in all Regions against suitable infestations (Hall, 1985; McMullen and others, 1986).

This bark beetle program was not intended to "control" the outbreaks; rather, activities were directed towards reducing the rate of loss, limiting the expansion of target infestations and allowing time to co-ordinate management plans to deal with outbreaks. Activities funded under the program were:

- accelerated access development;
- intensive aerial and ground surveys (including extensive use of 1:10,000 colour aerial photography);
- prioritized harvesting; and,
- concentrated single tree treatment programs in spot locations and on the leading edge of major outbreaks.

The use of semio-chemicals, in particular aggregation semio-chemicals, was integral to many of these activities. It was viewed that many of the activities and specific treatments directed towards mountain pine beetle would not be acceptably effective in reducing spread unless there was the ability to manipulate beetle populations fairly consistently. Semio-chemicals offered this opportunity.

Development of Baits

The Forest Service had limited experience in the use of this tool, but had been interested in and supported the development and refinement of these chemicals since the mid 1970's. At the inception of the bark beetle program in 1984, the position was taken that sufficient experimentation and trials had been done in British Columbia to establish their efficacy in certain use patterns (Borden and others, 1983A and 1983B; Conn and others, 1983). These previous trials were used to justify the extensive use of semio-chemicals in operational programs. It was also decided that their use or effectiveness would be monitored throughout the program and that their overall benefit to cost efficiency would be assessed in some detail during the overall program evaluation. This detailed evaluation is being undertaken during the 1988/89 fiscal year.

It should be mentioned here that the semio-chemical mix, currently in use, is not a perfect match to the naturally produced aggregation complex. However, this bait mix is consistent in inducing mass attack on baited trees. Further, the effective distance (50 m) between baited trees on a grid placement system appears to be effective in reducing or preventing escapes from baited areas.

Therefore, it was decided that the bait was effective enough in manipulating beetle populations that it could be used in certain well-defined use patterns to enhance beetle management efforts.

Rationale for the Use of MPB Semio-Chemicals

It is relevant at this time to go back a bit to review a previous bark beetle program in British Columbia during the early 1980's. In 1981, with both mountain pine beetle and spruce beetle, Dendroctonus rufipennis, on the increase in the Province, a two-year, $11.4 million program was implemented in an effort to establish some level of management. This program was terminated after one year due to the recession and fiscal restraint policies; however, some observations from this program pertain to the use of semio-chemicals.

Activities funded at that time were essentially the same as in the current program. One of the major differences, and possibly a major deficiency of the program, was the lack of use, or availability, of an operationally acceptable aggregation semio-chemical. Dispersal of beetles from population centres could not be predicted or managed with any precision. If infestations were not treated prior to the next beetle emergence period, extensive and expensive ground probing was required to locate new population centres potentially dispersed over larger areas.

In 1984, with a useable bait, the probability of success of a management program increased substantially. Manipulation of beetle populations enhances the effectiveness of beetle management activities. For instance, sanitation harvesting (as opposed to salvage) can be made much more effective in removing beetles from a stand, thereby reducing the risk of increasing infestation in neighbouring, susceptible stands. Similarly, in single tree treatment areas, beetles in those spots not dealt with prior to beetle flight, and residual beetles remaining in areas subsequent to treatment, can be arrested at pre-selected baited trees. Such restrictions on dispersal to predetermined areas greatly reduces the survey effort involved in locating population centres and reduces the size of treatment areas or cutblocks while addressing a larger proportion of a resident beetle population. Further, predetermining sites of newly attacked trees allows substantial increases in the use of MSMA (monosodium methanarsonate) - a treatment both faster and cheaper than conventional fall and burn efforts.

The use of baits should be integrated with hazard and risk assessments. Hazard ratings attempt to measure the susceptibility of a stand

should it become infested, while risk estimates the probability of a stand becoming infested. In effect, risk rates the beetle's "pressure" in a particular area. In a manner of speaking, semio-chemicals allow us to manipulate risk while harvesting strategies manipulate hazard.

A general principle of semio-chemical use should be emphasized. These baits are tools to be integrated with all other available tactics to achieve rather specific objectives. They are not a treatment unto themselves as, when used alone, they do nothing to reduce beetle population levels. In fact, the converse may be the case. Without subsequent follow-up, beetle populations may increase, and damage in terms of volume killed may increase as well. Semio-chemical baits, by definition, restrict dispersal and therefore reduce the proportion of beetles which would die through the dispersal process. Greater numbers of beetles will find suitable host material resulting in larger subsequent generations and attack levels. More trees may be attacked within a baited stand than may otherwise be the case. Further, as baiting criteria stress selection of the largest trees in an area, brood production may be greater per tree and the diameter distribution of attacked stems in a stand may be higher than normal. Therefore, the need for follow-up action, subsequent to the application of baits, must be clearly acknowledged at the inception of any management program.

Use of MPB Semio-chemicals in British Columbia

In British Columbia, semio-chemicals are being used extensively for two primary purposes:

1) for containment of beetle populations within proposed sanitation cut blocks; and,
2) as an aid in treatment of small infestation patches using single tree treatments (Heath, 1986B).

These uses do not require the "perfect" bait; rather, they depend upon the bait's consistency in inducing attack and resultant natural centres of attraction.

Purchase of baits under the bark program has been extensive in the past few years (Table 1). This level of use is expected to continue for the duration of the bark beetle program.

Table 1--Levels of Bait Purchases in the British Columbia Bark Beetle Program

Year	Number of baits Purchased[1]
1984/85	32,250
1985/86	63,400
1986/87	53,685
1987/88	44,500
Total	196,835

[1]Forest Service purchases only.

Expenditures on semio-chemicals have been significant. Purchase costs have varied somewhat from year to year due to pricing changes and bulk purchase discounts; however, an average cost per bait of $5.75 per year is reasonable. Other costs must also be considered.

Placement and overhead costs must be considered, especially in containment baiting. These have been roughly estimated as about $5.00 per bait. This cost includes placement in field, planning, storage/shipment, and some monitoring and assessment. This may be considered high as baits are often placed during other stand entries - still, it is a hidden cost. The total cost of using semio-chemicals is therefore about $10 - $11 per bait, especially in containment programs.

Containment baiting

Sanitation harvesting (i.e., logging and processing of stands with beetle brood producing trees) is the most efficient method of reducing beetle populations. Not only is a beetle population removed from an area, but values are received for the timber products.

If a block cannot be scheduled for cutting prior to the beetle emergence and flight period, significant emigration of the emerging beetles out of the block can often be expected. Peripheral stands will be attacked, or widely dispersing beetles may initiate additional infestation centers some distance away. The maximum effect of the sanitation cut will be lost: more trees will be killed; beetles may establish themselves in inaccessible areas; and, extensive and expensive surveys will have to be conducted to relocate and treat the escaped population. At this point, treatment of some stands may no longer be feasible.

This emigration of the target population can be reduced, or even prevented through the use of baits. Live, apparently susceptible trees within the block can be baited with semio-chemicals prior to the beetle flight period. When beetles emerge and begin searching for and attacking new hosts, the previously baited trees are usually the first attacked. Once baited trees are attacked, the natural attractant bloom produced by the beetles will further concentrate the population. Harvesting after the beetle flight period will therefore remove the resident beetle population (except those individuals left in stumps) and any beetles immigrating into the block as a result of the semio-chemical treatment. The use of aggregation baits will enhance the efficiency of sanitation logging and allow the removal and disposal of a greater proportion of the resident beetle population in an area.

British Columbia has been using two methods of baiting for sanitation logging. In smaller blocks, baits are put on trees at 50 metre grid intervals starting 25 metres in from the block

boundaries. Beetles emerging from brood trees should, therefore, be no further away from a baited tree than about 35 m.

The second method entails baiting trees 50 metres apart in two lines also 50 metres apart around the inside of the boundary of the proposed block. Areas where brood trees are concentrated within the block are baited on a 50 metre grid. Therefore, the bulk of the emerging beetles will find themselves in close proximity to baited trees and the remaining population within the treated area should either naturally find host trees within the block or be arrested at the periphery.

Use of baits is restricted by scheduling. Ground and aerial surveys are used extensively in late summer and winter to establish harvesting priorities based on access, merchantibility and infestation intensity. Blocks are identified, delineated, and cutting permits issued within a short time. Only blocks identified as having beetles, but that cannot be scheduled for harvest prior to beetle emergence are suitable for containment baiting.

Harvesting of these baited blocks is expected to occur during the year following baiting. Areas may be baited for successive years to hold beetle populations in place, but this is not done as a matter of course in British Columbia. There must be some plan for removal within a short period of time.

Evaluations of the effectiveness of containment baiting have not been extensive. As mentioned earlier, the decision was made at the outset of the program that efficacy had been shown and that monitoring and post- program assessments would occur on a continuing basis and at the end of the five year program.

The few formal evaluations of block baiting that have been made have supported the continued use of semio-chemicals for containment baiting(Gray and Borden, 1988; Heath, 1986A). A caution, however, is that a significant population of beetles should be present to justify treatment. The effectiveness of baits needs to be assessed further in regard to sparse or declining populations of mountain pine beetle.

Bait use in single tree treatment

The other major use of aggregation pheromones now employed in British Columbia is in augmenting single tree treatment projects such as fell and burn, or injection of MSMA. Single tree treatment projects are implemented to sanitize lightly infested stands, remove small patches in inaccessible areas or that cannot be removed through small volume timber sales, and to mop-up around the periphery of sanitation logging. This has been a large part of the current program (Table 2).

One of the most labour intensive and time consuming tasks in these types of projects involves finding and marking currently attacked trees containing viable brood. Semio-chemicals have greatly reduced this component and therefore make the work more efficient.

Table 2--Levels of Single Tree Treatments[1] in the British Columbia Bark Beetle Program

Year	Number of trees Treated
1984/85	40,231
1985/86	43,582
1986/87	57,619
Total	141,432

[1] Includes fall and burn, MSMA, and other methods.

It can be assumed (or assured) that sanitation logging will not remove all the beetles in a localized area. There have been many instances of cutting out infestations and then later finding small infested patches of trees around the periphery of blocks. Whether these beetles came from brood trees not included in the cut block or whether they represent the population remaining in stumps after cutting before the flight period does not really matter. These new patches do represent the potential for further damage to the surrounding stands and should be dealt with promptly if the stand is within a beetle control area.

Baits can be placed around the cut blocks during the final phases of logging. Blocks logged in the late summer or in the fall should be revisited early the following summer and baited. Baited trees in the stand surrounding a new cut block should be located about 25 m in from the edge and be spaced at 100 m intervals in the remaining susceptible type around the edge of the block. These baited trees will serve as aggregation foci and the residual beetle population in the area should be clumped around these predetermined spots. After the beetle flight period, attacked trees may be harvested with small timber sales, felled and burned, or, if treatment is possible within three weeks of attack, they may be treated with a hack and squirt application of MSMA.

Single tree treatment to sanitize stands not scheduled for harvest within a few years, or in remote areas where high value stands are threatened, is practiced in British Columbia to buy time. Again, the greatest expense is locating and marking the trees for disposal which may often require helicopter access and multiple entries for survey and location and again for treatment. The chances are that some trees will be missed and therefore not treated or that there will be some beetle production from remaining stumps or incompletely treated trees. Thus, further tree mortality should be expected in years subsequent to the initial treatment and the tactical use of semio-chemicals will make further treatments more efficient as the search time required will be substantially less.

When single tree treatments are done from late winter up to the beetle flight period, a few trees should be baited around the spot just as the site is left. These trees should serve as foci for aggregating the residual population and therefore additional trees attacked can easily be found and treated. Potential treatment sites can be identified and baited throughout the summer. The great reduction in survey time and efficiencies in pre-determining potential treatment sites more than compensates for the costs of bait placement.

MSMA offers an opportunity to treat infested trees quickly, easily, and cheaply. Estimates of costs for treatment by fall and burn range from \$20 per tree in areas with exceptional access to over \$100 per tree in areas requiring helicopter access. Province-wide, a rough average would be about \$50 per tree. In contrast, treatment costs for MSMA are less than \$10 per tree. The greatest constraint on the use of MSMA is the requirement to treat a tree within three weeks of the time of beetle attack (Dyer and Hall, 1979). After this, treatment is ineffective due to blocked translocation in the tree through colonization by blue stain fungi or because of larval feeding. Because of this narrow window for treatment, it is crucial to find newly infested trees quickly. Baiting trees serves to pre-select attacked trees and has enabled a rather large scale use of MSMA in British Columbia. For example, in 1987, approximately 12,000 trees were treated successfully with MSMA. Baiting trees also allows greater precision in scheduling activities and in defining treatment areas, necessary for obtaining pesticide use permits.

All assessments done to date indicate that baits are effective in limiting dispersal. It is our perception that baiting has made single tree treatment projects viable as a management tactic. Thoroughness and follow-up for a period of years, however, are prerequisites to such efforts.

Program Evaluation:

Quantitative and qualitative evaluations of the impact of semio-chemical use will continue. However, it is necessary to evaluate these chemicals within the context of the overall management program. In British Columbia, as stated earlier, the objectives of the current bark beetle program are to slow the rate of expansion of infestations, and to protect high value stands. Access and harvesting schedules are also modified to facilitate salvage, sanitation, and pre-emptive harvesting. Semio-chemicals are but one tool to be employed in a co-ordinated, integrated fashion with other activities. It will be necessary, therefore, to determine the effectiveness of the program as a whole and work backwards to show the contribution of baiting.

The greatest difficulty in determining the benefits of semio-chemical use, or any other aspect of a beetle management program, lies in defining what would have occurred without intervention. The initial justification for the program was based on continued, expanding attack throughout the high hazard pine at risk. This may have been overstated, as it is likely that:

- all susceptible pine would not have been attacked;
- in most cases stands that were attacked would not have been 100% destroyed; and,
- many of the attacked stands would have been harvested in any event and, therefore, potential actual loss would not be equal to total infested volume.

At any rate, losses were projected to be potentially large at least in the short-term (i.e. - 20 years). Long-term losses, or AAC reductions, were not anticipated. The main effect of the beetle outbreak was expected to be the removal of much of the mature age class component in specific affected areas. This would lead to timber shortages and potential mill closures while decimated stands were rehabilitated or regenerated naturally.

To estimate what would have happened without intervention, a number of techniques will be used:

1) in areas where consecutive annual 1:10,000 colour aerial photography has been taken, treated and untreated areas will be evaluated for rate of infestation increase, total area of infestation, and infestation dispersion;

2) detailed aerial and ground survey data from selected areas will be collated and tracked in relation to management activities to show progress. In effect, the intent is to indicate how effective the program was by detailing specific case studies and then extrapolating; and,

3) perhaps the greatest tool will be the use of various modelling efforts. Currently, a series of models which examine various aspects of mountain pine beetle/lodgepole pine interactions are being developed jointly by the Forest Service and the Canadian Forestry Service. When joined, these models will illustrate beetle dynamics in various pine types and the beetle's impact on timber supply. Different treatment scenarios can then be evaluated.

In terms of semio-chemical use alone, simulations should show the impact they have on limiting damage over the run of the model. It should be pointed out that one of the assumptions of the model is that semio-chemicals restrict dispersal; therefore, only their efficacy in reducing impacts through use in harvesting and single tree treatment programs can be evaluated.

Summary

Only observation and experimentation can confirm that existing baits perform as expected. In operational programs, however, some questions must be asked and answered:

1) Do semio-chemicals work and how well? Based on experimentation, field observation, and limited formal assessments, the existing baits are effective in arresting beetle flight. Baited trees are consistently attacked first in stands and serve as foci for the production of the natural attractant bloom.

   Further research is likely to refine the component mix of the bait to more closely resemble natural attraction. This will likely lead to improvements in the bait's effectiveness and possibly make the use of traps more appealing. However, further refinements would likely also lead to substantial cost increases. Use strategies employed currently take good advantage of the bait's effectiveness; even better baits may not justify possible cost increases. Traps would likely continue to have low useage, even if greatly more effective. Attractant semio-chemicals appear to have the greatest utility when integrated into harvesting or other similar conventional forestry practices.

2) Are the objectives of their use strategies realistic?

   Baits are used only to initiate attraction centres and restrict emigration of beetles out of target areas. As such, they are intended to manipulate localized populations in rather limited ways. These tools are not recommended for long range manipulations or for bringing populations in over large areas. Their use is to reduce the risk of beetle attack in adjacent stands.

   There is no doubt or argument that the most effective way of reducing losses to bark beetles over the long-term lies in manipulating the extent and type of the forest. However, both short and long-term strategies must be maintained.

   We have made the decision to deal directly with bark beetles rather than relying solely on stand manipulations to reduce long-term losses. Therefore, tools that allow us to manipulate beetles (i.e. risk) must be incorporated into management programs. As stated above, the effectiveness of the entire program is enhanced with the use of semio-chemicals.

3) Costs and gains?

   Costs of baits, even with a bulk purchase, have risen above the $6 per bait level. Therefore, in bait costs alone, restricting beetle dispersal from single tree treatment sites is about $25 per site and bait only costs for containment harvesting is about $25 per hectare - double this cost if overhead and placement costs are included.

   It is difficult to precisely quantify the gains versus these costs. However, we are now able to reduce survey/probe costs per site and increase the number of sites visited, treated, or harvested. Cut block sizes have been reduced as a result of baiting and, possibly most importantly, in many cases spots have not expanded beyond treatment or harvest capabilities. It is felt that the overall evaluation of the beetle program will reflect the value of semio-chemical use. Manipulation of localized beetle populations is integral to the efficiency of direct control.

4) Best circumstances? Worst?

   Application of semio-chemicals appears to work to greatest advantage in light to moderately infested stands where sufficient trees exist for baiting or in spot infestations where the intent is to arrest the dispersal of residual beetle populations. Baiting in the midst of extensive, heavy infestations may not be of great benefit as population pressure may overwhelm the baits in treated stands, and because attacks by surrounding populations would likely counter-balance any reductions resulting from containment baiting.

   There is some concern regarding use of aggregation baits in low level or endemic situations. Concentrating such populations may actually trigger an aggressive outbreak. Left alone, such populations may disperse and cause no problem. Although difficult to study, this aspect should be researched further. The concept of routinely aggregating and removing beetles as a matter of course during normal harvesting practices is appealing; it would maintain low risk and may pre-empt future outbreaks.

5) Risks associated?

   The greatest risk in use of baits lies in the necessity of ensuring follow-up action. The commitment and ability to ensure subsequent removal of infested material is key. This re-emphasizes the point that the use of baits or any other tool must be fully integrated into the overall forest management program.

Future use of semio chemicals will be dependent on the results of the current program evaluation and on additional research. Additional research should include examination of the effect of semio-chemical use on endemic populations and on the effect of beetle population vigour on the response to various bait formulations or placement strategies. Refinements to the existing formulation may also be of benefit as would research into the practicability of using repellants or anti-aggregation semio-chemicals.

The bark beetle program in British Columbia was designed to accomplish limited short-term objectives and indications are that the strategy was appropriate. Numerous examples exist in the Province where infestations have been brought under some measure of control when compared with other areas where no action was taken. The ability to manipulate beetle populations by limiting dispersal over large areas has played a significant role in this program.

Future management of pine will likely require an ability to deal with mountain pine beetle; long-term prescriptions cannot be totally effective. Semio-chemicals and other tools will be required and will be used to deal with specific circumstances.

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MOUNTAIN PINE BEETLE AGGREGATION SEMIOCHEMICAL USE IN ALBERTA AND SASKATCHEWAN, 1983-1987

H. F. Cerezke

ABSTRACT: A recent outbreak (1976-1986) of the mountain pine beetle, Dendroctonus ponderosae Hopk. in southwestern Alberta and Saskatchewan prompted control programs to be initiated in 1980-82 within three forested areas and involving three provincial agencies. The programs incorporated newly developed mountain pine beetle semiochemical tree baits during 1983 to 1987 to assist in the control strategies. A variety of information collected mostly in 1983 was used to help evaluate functional aspects of the tree baits for efficient detection, population monitoring and direct control. Data are presented on tree bait distribution, numbers of baits and their placement pattern, and incidence of attacks and attack densities on baited and adjacent unbaited trees.

INTRODUCTION

The recent mountain pine beetle (MPB), Dendroctonus ponderosae Hopkins, outbreak in southwestern Alberta was first detected in 1977 (Hiratsuka et al. 1980). It subsequently expanded rapidly northward along the eastern slopes of the Rocky Mountains, and attained maximum spread some 130 km north of the Canada-United States border by 1980-81 (Hiratsuka et al. 1982). During 1979 and 1980 numerous small but scattered infestations were discovered in the Porcupine Hills in southwestern Alberta, and in the Cypress Hills, an area straddling the southern Alberta-Saskatchewan boundary. The latter area is a distinct forested island isolated from the foothills region by over 200 km of intervening prairie agricultural zone (Newsome and Dix 1968). In addition, small infestation patches were observerd in 1982 in the Alberta foothills (Kananaskis area) directly east of Banff National Park. By 1986, after 10 years of outbreak period, MPB populations had declined to endemic levels at all locations in Alberta and Saskatchewan. Previous historical records of the MPB having occurred in either of these three areas was entirely unknown.

Prior to 1977, only two observational records had indicated that endemic populations of the MPB existed in southwestern Alberta during the late 1960's and in the early 1970's. The only previous recorded outbreak in Alberta occurred in Banff National Park between 1939 and 1944 (Hopping and Mathers 1945).

During the recent outbreak period in Alberta and Saskatchewan intensive salvage and control programs were initiated by the provinces in 1980-82 (Alberta Forestry, Lands and Wildlife 1986). The control programs consisted of detecting patches of infested trees, followed by destruction of live beetle broods by cutting, burning, bark-peeling and log processing at the mill. Semiochemicals of the MPB had previously been tested successfully in British Columbia and in the Cypress Hills (Borden et al. 1983a, 1983b, 1983c; Cerezke et al. 1984; Conn et al. 1983) and were incorporated initially into the control strategies by three different provincial agencies in 1983. This paper reviews the semiochemical tree baiting strategy from 1983 to 1987, describes the baiting results observed and offers some interpretations of the results.

METHODS AND MATERIALS

Control programs utilizing MPB semiochemicals were deployed in three general areas: Porcupine Hills and adjacent forested lands (PH); Cypress Hills (CH) in Alberta and Saskatchewan and in the Kananaskis (K) area directly east of Banff National Park (fig. 1).

All agencies deployed the same commercially prepared tree bait (Phero Tech Inc., Vancouver, B.C.), consisting of two MPB pheromone components and a host tree monoterpene. The objectives of the baiting program were: to test the tree bait as a reliable detection tool, and thus help reduce costs of subsequent aerial and ground surveys and tree treatments, and to test the baits for survey monitoring to indicate yearly trends of relative MPB abundance and as part of the direct control strategy of beetle population manipulation and/or reduction.

During the first year of semiochemical deployment (1983) an attempt was made to standardize the baiting procedure with the three provincial agencies (Alberta Forest Service, Alberta Parks and Recreation and Saskatchewan Parks, Recreation and Culture) to provide a basis for data analyses and interpretation. In subsequent years the pattern of bait

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H. F. Cerezke is Head of Forest Insect and Disease Survey, Northern Forestry Centre, Canadian Forestry Service, Edmonton, Alberta, Canada.

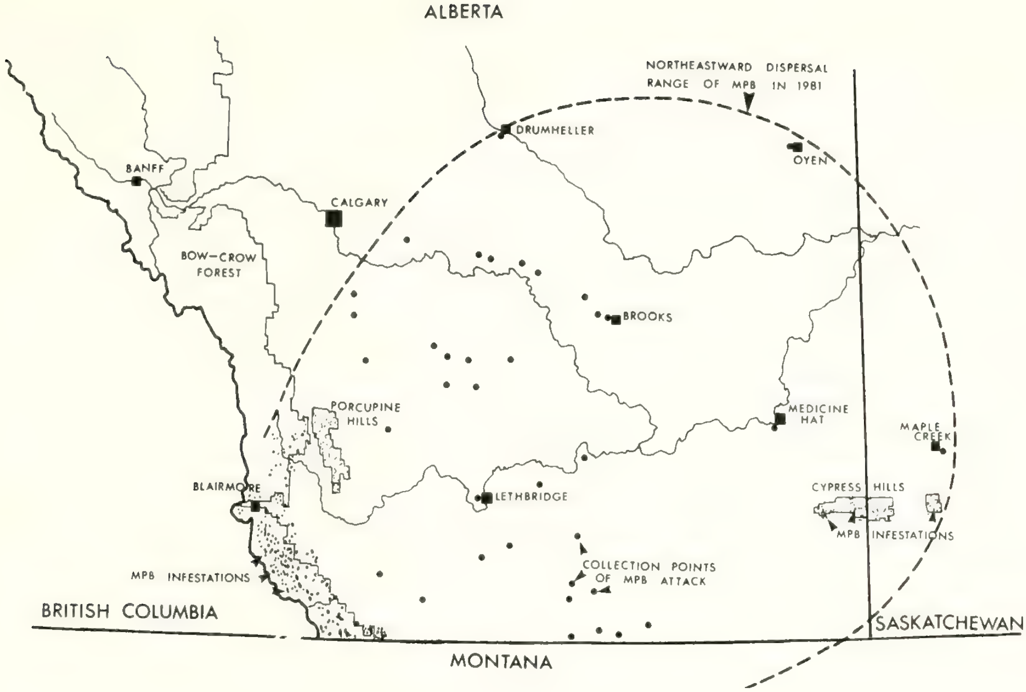

Figure 1--Map of southern Alberta and Saskatchewan showing the maximum extent of D. ponderosae (MPB) infestations in 1981, including the Porcupine Hills and Cypress Hills. Dots indicate collection points of MPB attacks observed on ornamental and shelterbelt planted pines.

distribution remained similar but with some variation in the number and location of baiting sites and in the number of baits deployed per site.

The guidelines adopted by each agency were as follows: baits were placed in mature lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) stands over 60 years of age and with an average DBH of 20 cm or greater in PH, CH and K control areas, and in a few limber pine (*P. flexilis* James) sites, also in the PH area. Various topographical sites were selected for baiting, including ridge tops, along creeks, on east-facing slopes and adjacent to clearcuts. The baits were placed one per tree on average stand diameter or greater size trees, 2 m above ground level and on the north aspect. Baits were distributed within a number of designated baiting locations (fig. 2) at which 5 to 21 baits were placed 50 m apart in mostly a single line transect or grid pattern. All baits were distributed prior to beetle flight and retrieved in late August or September.

At the end of the flight season all baited and adjacent unbaited trees within a 5-m radius of the baited tree were tallied. In addition, a measure of attack density was obtained on each baited tree and on adjacent unbaited trees by a count of the number of adult gallery initials within two 20x40 cm bark samples removed from each tree, both centered at bait placement level, one each on the north and south aspects. The samples were oriented with the long side vertically positioned on the stem and attack density was expressed as an average of the number of attacks per m^2 of bark surface.

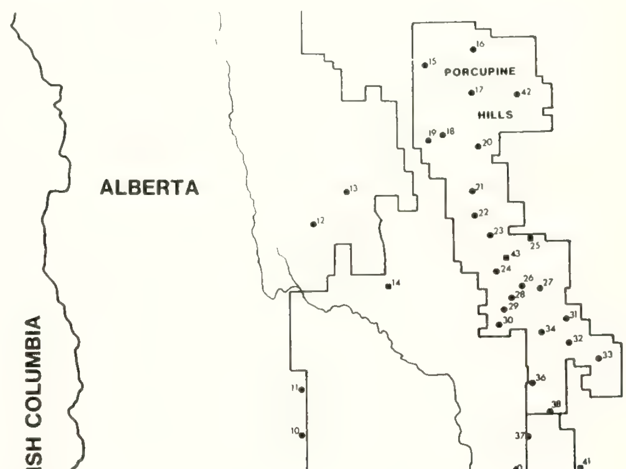

Figure 2--Distribution of D. ponderosae tree baiting sites in southwestern Alberta in lodgepole pine (dots) and limber pine (squares) stands in 1983.

RESULTS AND DISCUSSION

Figure 1 shows the distribution pattern of infestations of the MPB in southwestern Alberta, concentrated in stands of lodgepole pine and limber pine, and in lodgepole pine stands in the Cypress Hills. Collection points of MPB attacks within the agricultural zone were mainly on planted Scots pine (*P. sylvestris* L.), used extensively as an ornamental and shelterbelt species. The suggested northeastward dispersal range of MPB attacks extended some 200-300 km from the nearest population source and is assumed to have been aided by southwesterly flow wind patterns common during the time of beetle flight (Finklin 1986).

The semiochemical baits deployed and the numbers of selected baiting sites during 1983 are summarized in table 1. Numbers of tree baits used in subsequent years in the three control areas are given in table 2.

Populations were relatively high for the MPB in all control areas in 1983 as indicated by the high incidence of attacked baited trees (table 2). Many of the tree baits also influenced the aggregation of beetles onto large numbers of adjacent unbaited trees in over half of the baiting sites. Population declined sharply in most areas after 1984 (Moody and Cerezke 1986). While much of the control efforts of sanitation cuttings and tree bait aggregations to baited sites contributed to the population decline, severe winter temperatures during 1984-85 enhanced the success of the control programs by causing significant beetle mortality. The higher percentage attack incidence in 1987, compared to 1986, probably reflects higher overwinter survival of MPB, reduced numbers of baits in two of the control areas, and possibly the placement of baits into more selected baiting sites known to have populations.

The incidence of attacked baited trees in the Cypress Hills suggests there was a faster rate of decline after 1983 on the Saskatchewan side compared to the Alberta side. This may indicate a more direct population reduction due to concentrations of adult beetles onto baited and unbaited trees.

Table 1--Numbers of *D. ponderosae* tree baits and baiting sites deployed in 1983

Control areas	No. baiting sites	Baits per site (range)	Total no. baits
Kananaskis	7	10 (9-12)	71
Porcupine Hills and adjacent areas	41	10.3 (5-21)	423
Cypress Hills:			
Alberta	12	8.3 (5-20)	100
Saskatchewan	29	11.5 (5-20)	335

Attack densities of baited and adjacent unbaited trees are compared in table 3 and confirm higher attraction rates to the baited trees than to adjacent unbaited trees in all lodgepole pine and limber pine sites where data were available. Also, the percentages of attack incidence on north and south aspects of baited and adjacent unbaited trees were generally similar between the two groups in the different control areas and agree with similar published observations (Amman and Cole 1983).

An attempt was made to evaluate the efficiency of attracting MPB adults onto baited trees placed in a single line transect versus baited trees arranged in a grid (4 x 4 or 4 x 5) pattern. While average attack density was slightly higher on trees baited in a grid pattern the means of the two bait placement patterns were not statistically different. The results of this test, however, may vary with MPB population source and its nearness to the baiting site and with population abundance.

Table 2--Percentage of trees baited with semiochemicals that were attacked by *D. ponderosae* in three control areas during 1983 to 1987

Control areas	1983	1984	1985	1986	1987
Kananaskis and Porcupine Hills areas:	94 [1](494)	48 (2000)	- (1000)	15 (600)	55 (150)
Cypress Hills:					
Alberta:	100 (100)	48 (200)	19 (200)	3 (200)	10 (200)
Saskatchewan:	97 (335)	23 (1000)	10 (800)	0 (500)	1 (300)

[1]Values in brackets indicate the number of tree baits deployed each year.

Table 3--Summary of *D. ponderosae* attack densities and percentage of attacks on north (N) and south (S) aspects of baited and unbaited adjacent lodgepole pine (LPP) and limber pine (LMP) trees in three control areas in 1983

Control areas	Baited trees			Unbaited adjacent trees		
	Density/m^2	% attacks		Density/m^2	% attacks	
		N	S		N	S
Kananaskis (LPP):	62.4	62.7	37.3	44.2	45.4	54.6
Porcupine Hills and adjacent areas; (LPP):	64.1	53.4	46.6	46.8	56.5	43.5
(LMP):	117.1	47.9	52.1	72.4	50.2	49.8
Cypress Hills;						
Alberta (LPP):	100.2	53.8	46.2	[1]-	-	-
Saskatchewan (LPP):	76.6	54.3	45.7	61.7	51.0	49.0

[1]No data recorded.

A comparison was made between attack densities on baited trees in sites where few or none of the baited trees had associated adjacent unbaited attacked trees and with attack densities on baited trees in sites where 50% or more of the baited trees had adjacent unbaited attacked trees (table 4). This was to examine the likely relationship between MPB population source and abundance and the efficiency of the semiochemical attractants for concentrating beetles on to trap trees. Average attack densities in sites where 50% or more of the baited trees had adjacent unbaited attacked trees were all higher. The data support the idea that the numbers of beetles attracted to semiochemical tree baits are at least partly proportional to the surrounding population, and therefore indicate that the baits can serve as a reliable monitoring tool.

Sites in which different numbers of tree baits were deployed were arranged in classes of numbers of baits per site and plotted against average attack density (fig. 3). The data suggest that highest attack density on baited trees occurred where the numbers of baits was 4 to 6 and decreased to a constant density level when 10 or more tree baits per site were used.

Data on average attack densities in all lodgepole pine baiting sites in the Porcupine Hills were arranged according to topographical features in the landscape to help identify locations that may favor more efficient attraction and/or interception of dispersing MPB. While the data were highly variable some trends are apparent but would require additional field evaluation. Four topographical sites were selected to illustrate possible trends(table 5).

Table 4--Comparison of attack densities on baited trees having few or no adjacent attacked unbaited trees with baited trees having more than 50% of the baited trees with adjacent attacked unbaited trees

Control areas	Few or no adjacents			More than 50% adjacents		
	No. of sites	No. baited trees	Ave. attack density/m^2	No. of sites	No. baited trees	Ave. attack density/m^2
Kananaskis	4	40	33.9	3	30	[2] 97.5
Porcupine Hills and adjacent area	24	257	58.9	9	96	[1] 85.5
Cypress Hills:						
Alberta	9	75	95.7	2	15	[2] 120.3
Saskatchewan	15	175	58.6	12	135	[1]98.5

[1]Means with more than 50% adjacents were significantly higher ($p<0.001$; t-test).
[2]Means not tested because of low numbers of baiting sites.

Table 5--Average attack densities of D. ponderosae on baited lodgepole pine trees at selected topographical sites in the Porcupine Hills in 1983

Topographical sites	No. of sites	No. baited trees	Ave. attack density/m^2
East-facing slopes:	2	13	98.7
Adjacent to creeks:	4	43	95.8
On ridge tops:	5	38	69.9
Adjacent to clearcuts:	3	18	60.0

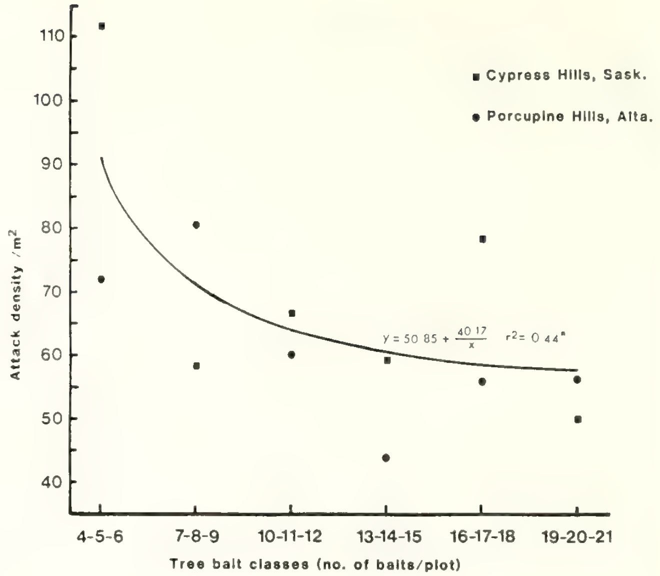

Figure 3--Numbers of tree baits deployed per baiting site (plot) in relation to D. ponderosae attack density on baited lodgepole pine trees.

SUMMARY

The integration of semiochemical tree baits into recent provincial programs to control MPB infestations in Alberta and Saskatchewan provided several important benefits in the overall control strategies. The baits induced aggregation of beetles into specific baiting sites which were often selected for easy access. Hence, infested trap trees could be easily monitored for control by sanitation cuttings during the same year. This allowed more time to be spent on locating isolated pockets of infested trees. The baits may have intercepted dispersing beetles both to and from the control areas. Attack densities on baited and adjacent unbaited trees appeared to vary directly with nearby sources of MPB populations, thus supporting the baits as a monitoring tool.

The baiting of selected sites provided substantial savings in "probe cruising", in search of random infestations, and also in reducing some aerial survey requirements. Depending upon the intensity and distribution of the baits throughout each control area, the aggregation of beetles onto baited and adjacent trees provided an indication of time of beetle flight, of relative population abundance, their geographical distribution and may also have indicated likely sources of populations such as in wind thrown trees and broken tree tops.

Data presented in table 2 suggest the baits may be sufficiently sensitive to detect small changes in population fluctuations when at endemic levels. This is an important aspect where eradication of the MPB from a forested area is the objective. Where only a few MPB induced attacks are successful, the individual galleries can be destroyed without killing the tree. For efficient detection and monitoring use in endemic populations only one, two or three baits per site are likely necessary.

ACKNOWLEDGMENTS

The author expresses appreciation to the many staff members of the participating provincial agencies who helped coordinate, conduct and record data for the integrated use of semiochemicals in the various control programs. In particular I would like to acknowledge Bruce Walter with Saskatchewan Department of Parks, Recreation and Culture, Tom N. Trott and Les E. Weekes with Alberta Recreation and Parks and Bob Miyagawa, Gordon Smith, Lou Foley and Hideji Ono with Alberta Forestry, Lands and Wildlife for their important coordinating and cooperative role.

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USE OF CHEMICALS TO PROTECT TREES FROM MOUNTAIN PINE BEETLE ATTACK

Patrick J. Shea

ABSTRACT: Preventative chemical strategies to mitigate the effects of mountain pine beetle depredations are reviewed. Various formulations and rates of carbaryl are shown to be effective in protecting individual lodgepole pine from successful attack by MPB. A 1% formulation of Sevin brand XLR will provide two years of protection. This is one half the registered rate. Results of field tests of various formulations of "pine oil" for individual tree protection indicate highly variable results. No further testing of "pine oil" is recommended because the manufacturer has suspended development.

INTRODUCTION

Chemical intervention to mitigate the effects of mountain pine beetle (MPB) (Dendroctonus ponderosae Hopkins) infestations has a long history. In a review of the history of chemical and mechanical tactics to suppress MPB infestations, Klein (1978) states that an oil formulation of naphthalene was the first chemical used against MPB (Salman 1938). This occurred in the mid-1930s and for the next 30+ years, a myriad of chemical insecticides were tested for MPB suppression. The chemicals tested for use in direct control programs included the following: DDT, lindane, ethylene dibromide, copper sulfate, aldrin, dieldrin, heptachlor and others.

During the mid-1960's it became apparent that efforts to control populations of MPB by spraying individual infested trees was an expensive and futile endeavor. Concurrent with this realization was an increased effort to develop insecticides for individual tree protection. The primary objective of individual tree protection is to protect standing live trees from bark beetle attack rather than kill beetles once they have successfully colonized a tree. Mortality of high-value trees located in campgrounds or other administrative sites can have long-range management effects. The value of these individual trees, cost of their removal, and loss of campgrounds can sometimes justify protecting individual trees until the main threat of an infestation subsides.

Lyon (1965) reviewed many of the early studies designed to prevent attack by bark beetles. In these studies many of the same compounds used in direct control strategies were tested for efficacy in preventing MPB attack of individual trees. Starting in the mid-70's there was a shift away from the chlorinated hydrocarbons and toward newer compounds. This change in direction was the result of at least two considerations: recognition of potential environmental problems associated with the chlorinated hydrocarbons, and discovery by Rodgers (1976) that oil formulations were phytotoxic especially to thin barked species of pine.

Recently research has demonstrated the effectiveness of several water based formulations of carbaryl for protecting individual trees from attack by bark beetles. Smith and others (1977) and McCambridge (1982) clearly demonstrated the effectiveness of a 2% formulation of Sevimol[R] in preventing successful attack by MPB on both lodgepole (Pinus contorta var. latifolia Engelm.) and ponderosa pine (P. ponderosa Laws.). Gibson and Bennett (1985) and Page and others (1985) confirmed these earlier results. It's of interest to note that research by Hall and others (1982) and Haverty and others (1985) demonstrated the same efficacy of water-based formulations of Sevimol for western pine beetle (Dendroctonus brevicomis Hopkins) on ponderosa pine.

There are several objectives to this paper. First, I will review the results of the most recent research on the effectiveness of carbaryl for preventing attack by MPB on lodgepole pine. Second, I will present some preliminary data covering three years of testing with several formations of "pine oil."

CARBARYL

In 1983, Shea and McGregor (1987) rigorously tested two water-based formations of carbaryl for effectiveness in preventing MPB attacks on individual lodgepole pine trees. This study was initiated because Union Carbide Corp. (now Rhone-Poulenc Inc.) had removed Sevimol from the market place. The study had two objectives: to compare the efficacy of Sevin brand XLR (the

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Patrick J. Shea is Principal Research Entomologist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, CA.

proposed replacement) with Sevimol, and to determine whether lower rates of Sevimol and Sevin brand XLR could provide acceptable protection with the same longevity.

The experimental design and subsequent analysis followed that described by Shea and others (1984). The two formulations were Sevimol and Sevin brand XLR, each applied at 0.5%, 1.0% and 2.0%. About 2.0 gallons of formulated material was applied to each treatment tree (ca. 0.02 gal/ft^2 of bark surface) in the early summer of 1983. The fate of each study tree was followed for two years with a separate set of control trees for each year.

In the fall of 1983, evaluations indicated that all treatments were effective (fig.1) in protecting the test trees from mass attack by MPB. Only one tree in the 0.5% Seven brand XLR treatment group died because of attack by MPB; none of the remaining trees in any treatment group were successfully attacked. Evaluations conducted in the fall of 1984 after two MPB flight seasons clearly indicated that the 0.5% formulations of Sevimol and Sevin brand XLR were beginning to fail (fig.2). However the 1% and 2% dosage rates of both formulations remained effective (>80% survival). This test demonstrated that managers can expect to achieve effective protection of individual lodgepole pine trees with a 1% formulation of either Sevimol or Sevin brand XLR. This concentration is one half the EPA registration rate (EPA Reg No 264-333) and represents a substantial cost savings and reduction of the amount of carbaryl being placed in the high-value,high use site.

Use patterns of this tree protection strategy in MPB infested areas vary greatly. Data from Loomis (1985) and other sources (personal communications) indicated that approximately 100,000 trees were treated for protection from MPB during 1979-1987 (fig.3). More than 80% of these trees were treated with a 2% formulation of carbaryl (probably Sevimol). However, during the field seasons of 1986, 1987, and 1988, USDA Forest Service individual-tree-protection programs have utilized the 1% concentration of carbaryl. For instance, personnel on the Deerlodge (1986) and the Flathead (1987) National Forests treated 1800 and 1200 campground trees, respectively, and report approximately 100% protection (personal communication with Region 1 FPM). Obviously these data have important economic and environmental implications.

PINE OIL

Recently there has been considerable interest, effort, and discussion concerning the use of "pine oils" as a repellent for protecting individual trees from attack by various species of bark beetles. "Pine oil" is a generic term referring to a complex mixture of naturally occurring or synthetically derived secondary and tertiary terpene alcohols and other terpene hydrocarbons. The naturally processed "pine oils" are refined by-products of the pulp and paper industry.

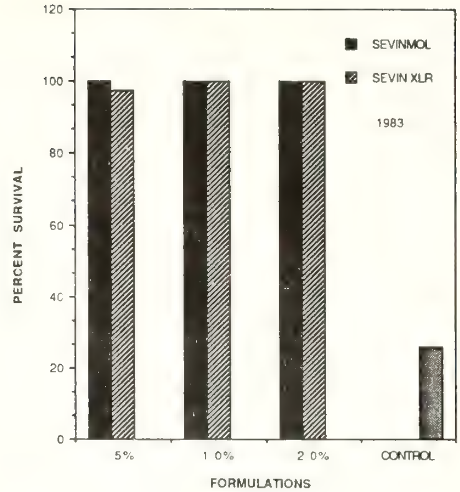

Figure 1--First year efficacy results of various rates of Sevimol and Sevin brand XLR after the 1983 field season.

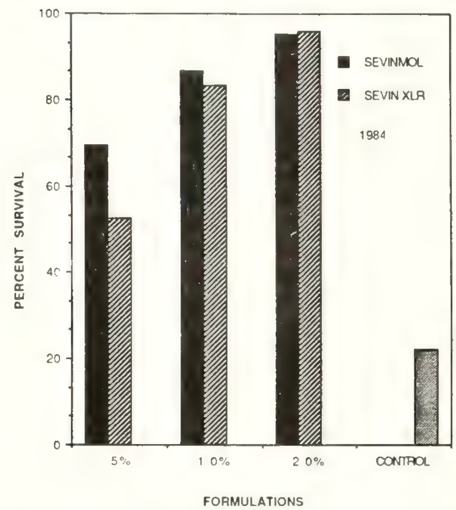

Figure 2--Second year efficacy results of various rates of Sevimol and Sevin brand XLR after 1984.

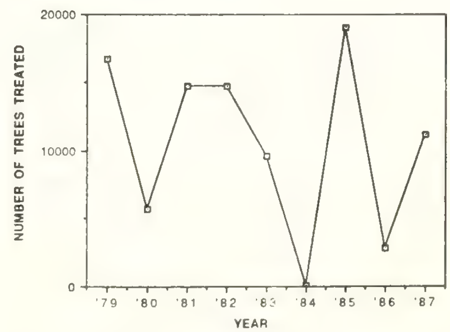

Figure 3--Use patterns of preventive sprays for mountain pine beetle 1979-1987.

Nijolt and McMullen (1980) first demonstrated that "pine oil", formulated as Norpine 65, could effectively prevent MPB from successfully attacking individual lodgepole pine. This was followed by a number of published reports indicating similar results on different populations of MPB (McMullen and Safranyik 1985; Richmond 1985) and other species of Dendroctonus (Nijolt and others 1981).

After considerable laboratory studies conducted to isolate the active fractions of Norpine 65, Mark McGregor (R-1, Entomologist) and I initiated field experiments to test the efficacy of various formulations for protecting individual trees from attack by MPB. These field tests were conducted because it was concluded, after discussions with representatives of Northwest Petrochemical Corp., that registration of Norpine 65, or any other unrefined formulation of pine oil, by EPA for individual tree protection would be a near impossibility. This conclusion was reached based on the nature of the Norpine 65 formulation with its numerous components, some of which had never been indentified, and the probability that each of these components would have to be subjected to numerous toxicological studies.

The design of these experiments follows that described earlier in Hall and others (1982) and Shea and others (1985). The tests were conducted during 1984-1986 in the Flathead National Forest of northwestern Montana. No synthetic baits were used in any of the experiments. A confidentiality agreement between the USDA/Forest Service and Northwest Petrochemical Corp. prevents, at this time, disclosure of specific contents in each formulation.

The results of 1984 tests are presented in figure 4. Greater than 60% of the control trees were successfully attacked indicating rigorous test conditions. None of the pine treatments met the predetermined success criteria that at least 24 of the 30 trees must survive to test the H_0:S(survival) $\geq$ 90% against H_a:S = 70%. Given a sample size of 30-35 trees these parameters provide a conservative binomial test (alpha = .05) to reject H_0 when more than six trees die. The Norpell, Fraction B and Fraction C formulations are all distillation tower refinements of Norpine 65P. The results obtained from Fraction B and Fraction C suggest that perhaps some attraction was occurring that resulted in highter attack rates on trees within these treatments when compared to the controls.

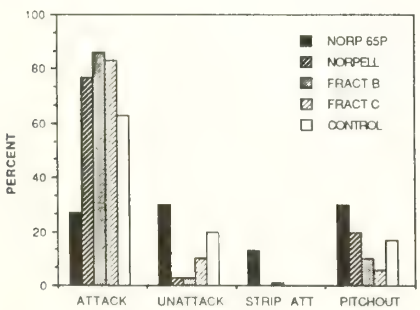

Figure 4--1984 results of various formulations of "pine oil" to prevent MPB attack on lodgepole pine.

Results of the 1985 field experiment (fig. 5) were similar to those obtained in 1984 in that all the treatments failed to provide adequate protection given the criteria described previously. However two things are of obvious interest. First the Norpine 65P formulation performed very poorly. Second the formulation Norpine M+O provides some suggestion of effect, given the high attack rate on the control trees and the percentage of trees not attacked or stripped attacked.

Finally, the results of the 1986 field experiments are presented in figure 6. The reduced sample size seriously affected the strength of the conclusions and was the result of a loss of trees due to firewood cutting and other uncontrolled events. Both the Norpine 65P and Norpine Poly M indicate considerable effectiveness. The protection provided by the Norpine Poly M formulation is especially noted because fully 80% of the test trees were not attacked at all in contrast to the Norpine 65P treatment where only

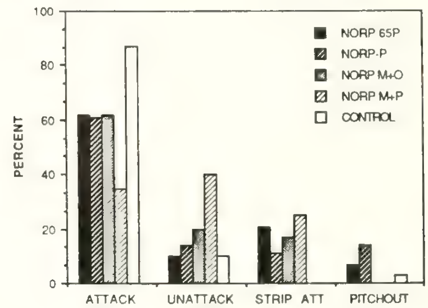

Figure 5--1985 results of various formulations of "pine oil" to prevent MPB attack on lodgepole pine.

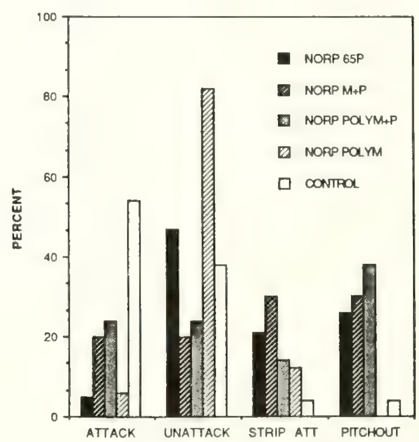

Figure 6--1986 results of various formulations of "pine oil" to prevent MPB attack on lodgepole pine.

47% of the trees were unattacked. These results would be especially encouraging if not for the fact that Northwest Petrochemical Corp. has experienced corporate difficulties unrelated to "pine oil" production and has decided to forego further development of this product.

Summarizing, preventive sprays for protection of individual high-value trees from attack by MPB is successfully employed throughtout the affected areas. Recent research and operational use has demonstrated that a 1% formulation (one half the registered rate) of carbaryl provides excellent protection. At the present time "pine oil" formulations do not appear promising as an alternative to insecticidal preventive sprays.

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REGISTRATION STATUS OF BARK BEETLE SEMIOCHEMICALS

Dennis R. Hamel

ABSTRACT: Tests of the semiochemicals verbenone and 3-methyl-2-cyclohexen-1-one (MCH) are continuing under experimental use permits. It is hoped that results will lead to registration consistent with the Federal Insecticide, Fungicide, and Rodenticide Act and the National Environmental Policy Act and use of these bark beetle semiochemicals as alternatives to conventional chemical pesticides.

INTRODUCTION

A full understanding of the processes leading to the registration of a compound as a pesticide requires the definition of several terms and the placement of them in proper context with their associated laws and regulations. This paper defines terms such as: a pesticide, pesticide research, experimental-use permit, pesticide registration, and exemption in the context of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), as amended. It also defines environmental analysis, scoping, categorical exclusion, environmental assessment, and environmental impact statement as related to the National Environmental Policy Act (NEPA). The paper concludes with an update of the registration status of two semiochemicals--verbenone, the antiaggregating pheromone of the mountain pine beetle (MPB), and methylcyclohexenone (MCH), the antiaggregating pheromone of the Douglas-fir beetle (DFB).

FIFRA

FIFRA is a Federal law that was passed by Congress in 1972 and substantially amended in 1974 and 1978. New revisions were considered in 1987 and 1988 but Congress has been unable to reach agreement on new changes to the Act. FIFRA is administered by the U.S. Environmental Protection Agency (EPA) and it provides national guidance for and regulation of the registration, manufacture, transportation, and use of all pesticides (herbicides, fungicides, fumigants, insecticides, rodenticides, etc.). FIFRA defines a pesticide as any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest (insect, rodent, plant, or other unwanted organism).

Section 3 of FIFRA provides guidance on the data required to register a pesticide. Data gathering is research. Preliminary research or testing is usually done in the laboratory and is called screening for potential pesticidal activity. Later, greenhouse and/or limited outdoor tests are done to further confirm pesticidal activity. While testing is being done to determine the value of a substance for pesticidal purposes, and when applications are on a cumulative total of less than 10 acres, a material is not considered a pesticide and no paperwork under FIFRA is required. However, once an active ingredient is determined to be efficacious and there is an interest in examining its potential for future operational use, then an experimental use permit (EUP) is required.

The purpose of EUP's is to provide EPA some oversight (FIFRA Section 5) during the generation of data necessary to support an application for full registration (FIFRA Section 3). The process is also intended to prevent adverse environmental impact by preventing the indiscriminate use of potentially dangerous materials without the restraint and control of regulatory protocols that prescribe plot size, geographic location, and amount of active ingredient intended to be used under the EUP. When a material is being evaluated for its pesticidal potential on more than 10 acres, EUP's are essential. This goes for conventional chemical pesticides, biologicals, and semiochemicals. Exceptions exist when the Administrator of EPA grants an exemption.

Such was the case in 1987 when EPA, after long negotiations with the USDA Forest Service and Phero Tech, Inc., changed its policy and allowed tree baits, which had previously required registration, to be exempt. EPA has not, however, exempted semiochemicals that are sometimes formulated as beads and used in broadcast applications.

NEPA

NEPA is a Federal law passed by Congress in 1969 to encourage Federal agencies to conduct their programs in ways that will create and maintain conditions under which people and nature can exist in productive harmony now and in the future. It also requires a systematic, interdisciplinary approach to planning and decision making for

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Dennis Hamel is Pesticide Specialist, Forest Pest Management, Pesticide-Use Management and Coordination Group, Forest Service, U.S. Department of Agriculture, Washington, DC.

actions that may affect the quality of the human environment. Federal agencies are required to study, develop, and describe appropriate alternatives to proposed courses of action under NEPA.

The process of analyzing a proposed course of action and developing alternatives is called environmental analysis. The method of collecting public input (in terms of issues, concerns, and opportunities) is called scoping. Scoping determines the extent of environmental analysis necessary. The result of these two activities leads to documentation of a decision.

Depending on the nature of a proposed Federal agency project, NEPA documentation may take one of three forms: (1) categorical exclusion (CE), (2) environmental assessment (EA), or (3) environmental impact statement (EIS). Categorical exclusions are reserved for actions that, based on both experience and environmental analysis, will have no significant impact on the quality of the human environment, individually or cumulatively (e.g., administrative road closures, construction of low-impact facilities, repair and maintenance, etc.). It is not a good practice to use CE's for most pesticide-related activities. Environmental assessments are used to document the analysis of an action not categorically excluded from documentation but for which the need for a more extensive environmental impact statement has not been determined. EIS's are comprehensive reviews of factual information that provide a responsible official with all of the information, necessary to make an informed decision. Some EIS's contain risk assessments and worst case analyses when they deal with subjects about which there is scientific uncertainty or unknown information. This is often the case with pesticides.

BARK BEETLE SEMIOCHEMICAL REGISTRATION STATUS

The USDA Forest Service (FS) has pioneered or assisted in pioneering research on the identification and development of several bark beetle semiochemicals. For example, in the early 1970's FS researchers identified, isolated, and synthesized 3-methyl-2-cyclohexen-1-one (MCH), the antiaggregating pheromone of the Douglas-fir beetle. More recently the FS cooperated in the research and development of 4,6,6-trimethylbicyclo (3.1.1) hept-3-en-2-one or verbenone, the antiaggregating pheromone of the mountain pine beetle.

MCH

Initial laboratory testing of MCH by the FS did not require FIFRA paperwork; however, in 1978 the FS requested an EUP from EPA. The EUP was granted (No. 27586-EUP-23) and the FS expects to continue operating under an extension to this EUP until May 1990.

In 1986, the FS, based on data collected under the EUP, requested full registration of MCH. In 1988, EPA notified the FS that additional research was needed. Unable to conduct the necessary research itself, the FS requested input from interested parties in the private sector by advertising in the Commerce Business Daily (June 8, 1988). Four firms expressed interest in production and marketing of MCH and negotiations are in progress to transfer this technology under the auspices of the Stevenson-Wydler Technology Transfer Act. Use of MCH is very limited at present, and no NEPA documents covering use of this compound have been prepared to date.

VERBENONE

Basic research on verbenone has been conducted primarily in Canada at Simon Fraser University and at Phero Tech, Inc.; however, the FS has been an active cooperator in the research and development of this MPB-antiaggregating pheromone. In 1988, Phero Tech, Inc. requested and was granted an EUP (No. 56261) for evaluation of bubble cap (EUP-1) and bead (EUP-2) formulations. These EUP's will serve to facilitate small-scale field studies of verbenone over the next 2 years. Currently the FS is cooperating on a replicated research study in Regions 1, 2, 4, and 6 as described by Amman and others at this meeting. An EA was developed by the Intermountain Research Station for this effort.

It is hoped that, consistent with FIFRA and NEPA, the results of these efforts will lead to the future registration and use of bark beetle semiochemicals as viable alternatives to conventional chemical pesticides.

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Amman, Gene, D., compiler. 1989. Proceedings--symposium on the management of lodgepole pine to minimize losses to the mountain pine beetle; 1988 July 12-14; Kalispell, MT. Gen. Tech. Rep. INT-262. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 119 p.

Includes 25 papers summarizing latest information on risk assessment, planning, management strategies, and suppression practices for the mountain pine beetle, a major cause of lodgepole pine losses in large forest areas of the Western United States and Canada.

KEYWORDS: Dendroctonus ponderosae Hopkins, Pinus contorta Douglas, risk assessment, ecology, biology, survey methods, stand management, wood utilization, insect suppression, semiochemicals

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

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Forest Service

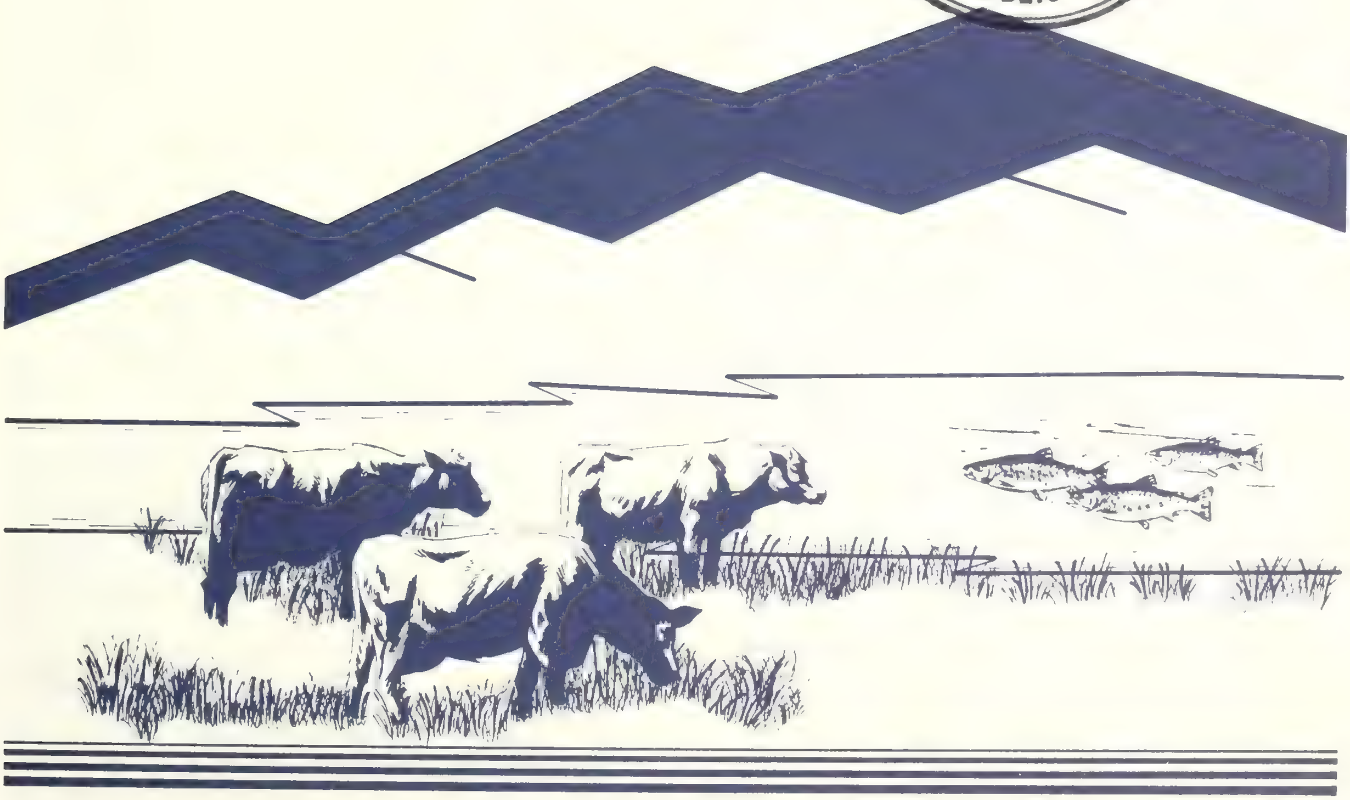
Intermountain Research Station

General Technical Report INT-263

May 1989

Managing Grazing of Riparian Areas in the Intermountain Region

Warren P. Clary
Bert F. Webster



THE AUTHORS

WARREN P. CLARY is project leader for the Riparian-Stream Ecosystems research work unit at the Intermountain Station's Boise, ID, Forestry Sciences Laboratory. He has a B.S. degree in agriculture from the University of Nebraska, and an M.S. degree in range management and a Ph.D. degree in plant ecology from Colorado State University. He joined the Forest Service in 1960 and has conducted research on forested and nonforested rangelands in Arizona, Louisiana, Utah, Idaho, Oregon, and Nevada.

BERT F. WEBSTER is range, wildlife, and fisheries staff officer for the Sawtooth National Forest, Intermountain Region, Forest Service, Twin Falls, ID. He has a B.S. degree in range management from Utah State University. He joined the Forest Service in 1961. He served as a range conservationist in Wyoming and Idaho, as a District Ranger in Nevada and Idaho, and on the Regional staff for range adminstration and improvements.

FOREWORD

The riparian grazing management recommendations in this paper are intended as guidance for planning and implementing riparian grazing procedures on National Forest System lands in the Intermountain Region. They are general criteria that with some modification and site-specific adjustments can be applied to a variety of situations. The application of these basic concepts along with riparian standards and guidelines in a Forest Plan will achieve the desired objective of healthy riparian systems.

J. S. Tixier
Regional Forester
Intermountain Region

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Intermountain Research Station
324 25th Street
Ogden, UT 84401

Managing Grazing of Riparian Areas in the Intermountain Region

Warren P. Clary
Bert F. Webster

INTRODUCTION

This paper was prepared as a guidance document for planning riparian grazing procedures on National Forests of the Intermountain Region of the Forest Service, U.S. Department of Agriculture. Much of the supporting information is broadly based; therefore the recommendations should be applicable beyond the Intermountain Region. Recent research information on grazing systems and grazing-riparian interactions was combined with our experience in various areas within the Intermountain Region to form a basis to guide future riparian grazing management.

These riparian grazing management recommendations have been developed as an aid in reducing nonpoint source pollution in western streams and as suggestions that could be incorporated in appropriate State Best Management Practices. "Best Management Practices" (BMP) means a practice or combination of practices that are determined by a State or designated areawide planning agency to be the most effective and practical means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality and related riparian-stream habitat goals. These are determined after problem assessment, examination of alternative practices, and appropriate public participation (Federal Register 1975). Designation of grazing management actions as Best Management Practices to protect water quality requires approval by the water quality management agencies of individual States. The Forest Service's Intermountain Region and the Intermountain Research Station are coordinating with the States within their respective boundaries to incorporate appropriate management into the States' recognized Best Management Practices.

The recommendations in this document are generic: they are general criteria that can be applied to a variety of situations. Selection of specific actions to accomplish the required result on a site-specific basis should normally be made by the land/resource/livestock managers based on soils, climate, special problems, management objectives, and water quality requirements. The recommendations may also be useful guides for reduction of grazing impacts on other resources in addition to reduction of nonpoint source pollution.

BACKGROUND

Improper livestock management, through excessive grazing and trampling, can affect riparian-stream habitats by reducing or eliminating riparian vegetation, causing channel aggradation or degradation, causing widening or incisement of stream channels, changing streambank morphology, and as an accumulative result often lowering surrounding water tables (Platts 1986). Once a riparian-grazing problem has been identified, the possible solutions depend upon the following (Skovlin 1984): How depleted is the riparian and aquatic habitat? How critical is the habitat for riparian-dependent resources such as water quality, fisheries, or recreation, and does the habitat contain any threatened or endangered species? What is the timetable goal for restoration? And what level of restoration is acceptable for reinstituting grazing?

A six-step planning process for grazing riparian zones has been suggested (in part from Dwyer and others 1984): (1) determine what factor, such as bank instability or loss of woody plants, is of primary concern, (2) determine site potential and capability, (3) determine the suitability of the affected sites for livestock grazing, (4) determine the kind and class of livestock and duration and intensity of livestock grazing best suited to the area, (5) determine the best grazing strategy, and (6) apply the proper grazing intensity in keeping with animal distribution patterns.

Livestock Grazing

Interest is high concerning livestock grazing, particularly cattle grazing, on riparian habitats. Grazing systems typically used for riparian areas are similar to those developed to maintain or improve conditions of upland vegetation types. However, no grazing system has been devised for ensuring proper use of small riparian meadows within extensive upland range. In addition, the most recent information on grazing uplands suggests that although conventional grazing systems have great intuitive appeal, they are less effective at maintaining ecological quality and livestock production than previously thought (see appendix I).

The most obvious benefit of a grazing system is to help provide the necessary livestock control to do a good management job. **The level of utilization occurring on a site—including riparian areas—is the most important consideration.** In fact, most riparian grazing results suggest that the specific grazing system used is not of dominant importance, but good management is—with control of use in the riparian area a key item (see appendix II). Specially designed grazing systems that control degree and timing of use in the riparian area can be highly beneficial.

Another item of importance is season of use. Spring grazing of riparian areas has several advantages (see appendix II). Grazing early usually results in a better distribution of use between the riparian area and adjacent uplands. This is likely due to more similarity in vegetation succulence between riparian and upland areas than would be the case later in the season, cooler temperatures in the early season, and in some cases livestock may avoid streamside areas that are often wet in the spring. Early grazing, followed by complete livestock removal, allows riparian plant regrowth to occur before the dormant period in the fall. Fall grazing is a second choice in most areas but is probably acceptable if utilization levels are carefully controlled to leave protective vegetation cover for the following winter-spring high streamflow periods. Grazing riparian areas during the summer should be limited or carefully controlled because of the strong tendency of cattle to concentrate there in the hot and often dry months.

Managers of rangelands are accustomed to giving primary consideration to plant physiological vigor. **However, a major additional need in most riparian areas is to consider the requirements of other riparian-dependent resources including maintenance of streambank structure and channel form—key factors in fisheries habitat and hydrologic function.** Careful control of grazing pressure results in maintenance of the streambank vegetation and limitation of trampling, hoof slide, and accelerated streambank cave-in (see appendix II). Residual streamside vegetation biomass encourages trapping and deposition of sediments as a basis for maintaining or rebuilding streambanks. Concentrated livestock use, as often occurs in uncontrolled season-long continuous and certain rotational grazing systems, may cause unacceptable damage to woody plants and streambank morphology.

Recent On-the-Ground Experience

In a recent inventory of almost 250 miles of National Forest riparian areas, no single grazing strategy was found to be effective in every riparian situation (USDA FS 1987). However, a few key points seemed to be important. Grazing conflicts with riparian-dependent resources were usually not severe in type A stream channels or in most type B stream channels (stream types identified by Rosgen 1985). Generally, these stream channels are in narrow valleys occupied by woody species and are armored by rocks providing resistance to erosion and trampling damage. The greatest conflicts occurred in type B channels with medium- to fine-textured, easily eroded soil materials and most type C channels. The latter channel types are typically associated with meadow complexes that are attractive to livestock and are often important fishery habitats. In these channel types a vigorous plant community is important for protecting streambanks against erosive forces and for trapping sediments (Swanson 1989).

Riparian areas associated with medium- to fine-textured B channels and most C channels were generally: (1) in a late seral status if they were only grazed in the spring or, if grazed in the fall, the fall grazing was light and late in the season; (2) in a mid seral status where summer grazing was light; and (3) in a late or improving seral status with vigorous riparian species and stable streambanks after receiving complete rest for several years (see appendix III for description of seral status). Reduction of shrubs in the riparian plant community appeared to be due to grazing of young reproduction age classes rather than due to the mechanical damage to the older shrub age classes by rubbing and bedding.

GRAZING MANAGEMENT RECOMMENDATIONS

Once it has been determined that livestock grazing can and should continue on a particular riparian area, management practices in any grazing system must provide for regrowth of riparian plants after use, or should leave sufficient vegetation at the time of grazing for maintenance of plant vigor and streambank protection. To achieve this **it is recommended that a minimum herbage stubble height be present on all streamside areas at the end of the growing season, or at the end of the grazing season if grazing occurs after frost in the fall. The residual stubble or regrowth should be at least 4 to 6 inches in height to provide sufficient herbaceous forage biomass to meet the requirements of plant vigor maintenance, bank protection, and sediment entrapment.** Also, for pastures grazed in the fall, the retention of this standing crop of herbaceous forage will normally detour significant feeding on willows and most other riparian woody plants (see appendix II). The stubble height criterion should be adhered to regardless of the grazing system used. To help achieve this goal:

1. On most National Forest pastures grazed in spring only, utilization of streamside herbaceous forage should be limited to about 65 percent of the current growth, and livestock should normally be removed by July 15 to allow sufficient time for plant regrowth. On lower elevation National Forest pastures the appropriate spring removal date may be substantially earlier.

2. Streamside utilization of herbaceous forage in summer-grazed pastures should not exceed 40 to 50 percent of the current growth.

3. Fall use of streamside vegetation should not exceed about 30 percent, and the herbaceous stubble remaining at the end of the grazing period should meet the 4- to 6-inch criterion.

4. Season-long grazing should be limited to those situations where animal use and distribution can be carefully controlled, such as by the use of riparian or other special use pastures, and where the stubble height requirements can be met.

5. Special situations such as critical fisheries habitats or easily eroded streambanks may require stubble heights of greater than 6 inches.

The utilization guides for these recommendations are based on use in pastures in good to high ecological status and on information in appendix II.

Degraded riparian areas may require complete rest to initiate the recovery process. In systems requiring long-term rest, the rest period will be highly variable

depending upon the situation. It may be as short as 1 year or it may be 15 years or longer. Recovery of degraded streambank form usually will require more time than the recovery of plant community composition, in some cases much more time, particularly if the channel has become incised and confined. Once an area has improved to a mid or late seral status through the use of rest or careful management, rotation management systems may allow riparian habitats to remain in good condition while being grazed. However, no rotation system will allow recovery or maintenance of the riparian system unless all livestock are removed after the use period. In any event, rest-rotation or any other conventional grazing system should not be considered the sole answer to riparian grazing needs.

Riparian area managers must have a commitment to do whatever is necessary to control livestock use and distribution. A wide variety of management techniques are available to do this including establishment of special use riparian pastures, development of alternate water sources away from riparian areas, location of stock driveways outside of these areas, periodic herding of livestock away from the areas, salting outside of riparian areas, and other common range management practices that may help reduce concentration of livestock. Whatever approach or approaches are used will likely be successful if use rates are carefully controlled and, if possible, grazing is avoided during mid and late summer.

The practices described in this section should provide for plant and streambank requirements under most grazing situations. The specific management approach used to meet the recommendations will need to be determined on a site-specific basis. Physical factors such as stream type, geology, climate, and elevation greatly influence the recovery of riparian areas. Therefore, the specific management action must be tailored to fit local conditions.

Monitoring should be an integral part of any management change designed to improve riparian habitats. When recovery does not occur or is progressing too slowly, further changes in management practices are warranted.

SUGGESTED INITIAL ACTIONS

Ecological Status - Early Seral

1. "A" and most "B" channel types (inherently stable types):

   Apply rest or the recommended riparian grazing management practices until the ecological status improves.

2. "B" channel types with medium to fine easily eroded soil materials and most "C" channel types:

   Apply rest until the ecological status improves.

Ecological Status - Mid Seral

1. "A" and most "B" channel types (inherently stable types):

   Continue present management or apply the recommended riparian grazing management practices.

2. "B" channel types with medium to fine easily eroded soil materials and most "C" channel types:

   Apply the recommended riparian grazing management practices.

Ecological Status - Late Seral

1. All types:

   Continue current management or apply the recommended riparian grazing management practices.

Environmentally Sensitive Areas

1. Streambanks subject to early season grazing damage:

   Where a combination of high soil moisture and fine soil texture results in streambanks susceptible to trampling damage, grazing may need to be delayed to a late season period. The herbaceous stubble height criterion would still apply.

2. Habitats where threatened, endangered, or sensitive species occur, or where streambanks/channels are highly erodible:

   The herbaceous stubble height criterion may need to be increased to greater than 6 inches. Under extreme conditions, the area may need permanent protection, or at a minimum, grazing may need to be removed for long periods.

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APPENDIX I: GENERAL REVIEW OF GRAZING SYSTEMS

The sensitivity to grazing of many Western native forage plants was recognized in the early 1900's, but realization of the significance of this developed slowly, and serious application of known information lagged. For 30 years grazing systems have been advocated by public land management agencies for use on Western ranges in the hope of achieving better livestock distribution, greater herbage and livestock production, and improved range condition. Grazing systems, which combine periods of use and nonuse, were originally proposed to improve ranges that had deteriorated under improper grazing (Hormay and Evanko 1958). A grazing system is defined as "A specialization of grazing management which defines systematically recurring periods of grazing and deferment for two or more pastures or management units" (Range Term Glossary Committee 1974). Deferred-rotation, rest-rotation, high intensity-low frequency, and short duration are forms of grazing systems (Kothmann 1984).

Past reviews of grazing systems have pointed out, first, that grazing systems were originally proposed as a means to improve deteriorated ranges through judicious use of seasonal grazing and periods without grazing. Second, more emphasis is being given to grazing systems as means to increase animal productivity. Third, grazing systems facilitate application of other range improvement practices such as fencing, water development, brush control, and seeding. The review papers point out, however, that (1) every grazing system has shown a wide variation in attaining improvement in range condition, (2) livestock productivity has varied from significant increases to significant decreases when systems were compared, (3) differences in results have been inconsistent and unexplained, (4) grazing systems that do well on one kind of rangeland may not work at all in another region, and (5) few analyses of the cost effectiveness of grazing systems have been made (Heady 1984). The one certainty is that there is no single grazing system that will improve rangeland everywhere (Dwyer and others 1984).

The success of grazing systems depends in part upon managerial control of time, place, and degree of forage utilization. The new fencing and additional livestock watering points that are required to initiate a grazing system also result in smaller pastures, better distribution of animals, and hence more even use of the forage plants across the pasture. Movement of animals from one pasture to another gives the manager some control over severity and timing of use (Heady 1984). These systems with additional pastures and movement of livestock often provide incentive and opportunity for vegetational manipulations such as brush control, seeding, and pitting, which can result in improved range condition and livestock production. Confusion occurs when results are ascribed to the grazing system when in fact they are due to the whole range management program (Heady 1970). Laycock and Conrad (1981) provided a case in point. Their study compared native sagebrush-grass range summer-long grazing every year, summer-long every other year, and a three-unit rest rotation system. Plant cover, production, and composition, and average daily gains of cattle were similar after 7 years of study. The key to this result was that each system had adequate fencing, good distribution of water and salt, and adequate riding to ensure uniform cattle distribution. In other words good range management was practiced regardless of the grazing system. Unfortunately, results of whole range management programs have often been attributed to grazing systems alone (Heady 1970).

Numerous hydrologic studies have upheld the conclusions of Blackburn and others (1982), who stated that little information supports claims for grazing systems. In a review of recent studies, Pieper and Hietschmidt (1988) found no results to suggest that the application of short-duration grazing has a different effect on hydrologic performance and soil characteristics than does any other grazing system. They concluded that heavy stocking would result in long-term downward trend in hydrologic characteristics and that vegetation growth response in a short-duration grazing system is similar to that expected from any other grazing system. There was no consistent advantage for individual livestock gains under short-duration grazing on arid and semiarid rangeland. The authors concluded that much of the success attributed to short-duration grazing is not directly attributable to that system but rather to improved overall management. They suggested that stocking rate is and always will be the major factor affecting the degradation of rangeland resources. No grazing system can counteract the negative impacts of overstocking on a long-term basis.

Generally, defoliation reduces the capacity of a plant to grow. A corresponding reduction in production usually occurs as either the frequency or intensity of defoliation increases (Trlica 1977). Vegetation appears to be more affected by grazing intensity than by grazing systems. Van Poollen and Lacey (1979) reviewed 18 studies comparing continuous grazing and the implementation of grazing systems at a moderate rate of use, and they compared 14 studies on grazing intensities of light, moderate, and heavy rates. Their analysis showed a 13 percent increase in forage production in favor of grazing systems over continuous use. However, the herbage production response to reductions in grazing intensity was much greater. Reduction in level of use from heavy to moderate increased production 35 percent, while reducing use from moderate to light increased production 28 percent. This value is in line with a review of herbage production that showed grazed areas usually produced less than 800 lb per acre, while ungrazed areas often exceeded 1,200 lb per acre (Clary 1987a). Such results suggest that managers should place more emphasis on proper stocking intensity and less on grazing system implementation (Van Poollen and Lacey 1979). The concentrated use of grazed pastures is not compensated for during rest years if grazing use is heavy (Eckert and Spencer 1986, 1987).

In summary, although grazing systems have great intuitive appeal, they are apparently of less consequence than once thought. In fact, as long as good management is practiced so that there is control of livestock distribution and grazing intensity, the specific grazing system employed may not be significant.

APPENDIX II: CURRENT INFORMATION ON GRAZING RIPARIAN AREAS

Although some riparian areas are resistant to damage from grazing livestock, others are vulnerable. If damage occurs it usually includes reduction or elimination of riparian vegetation, modifying streambank and channel morphology, increasing stream channel width or incisement, increasing stream sediment transport, and lowering surrounding water tables. Few examples exist of careful grazing system study within riparian areas. Numerous case history studies and experience of a variety of people suggest that no specific grazing system has proven universally successful.

Grazing Effects

Documentation shows that cattle, given the opportunity, will spend a disproportionate amount of time in a riparian area as compared to adjacent xeric upland areas. This may be five to 30 times higher than expected based on the extent of the riparian area. Features that contribute to higher use levels in riparian areas are: (1) higher forage volume and relative palatability in the riparian area as opposed to the uplands, (2) distance to water, (3) distance upslope to upland grazing sites, and (4) microclimatic features (Skovlin 1984).

Although many of the riparian-fisheries-grazing studies have been deficient in design, measurement, or documentation (Platts and Raleigh 1984), a great deal of case history and observational information has been accumulated. Concerning grazing impacts on riparian areas, four components were most often studied: (1) fish habitat in the aquatic system, (2) woody vegetation components of the riparian area relating to fish and bird habitat, (3) herbaceous utilization and grazing levels that can influence yields of plants, small mammals, and invertebrates, and (4) watershed conditions of cover and soil compaction on the floodplain and runoff from upland range (Skovlin 1984).

Platts and Raleigh (1984) summarized direct effects of livestock grazing:

1. Higher stream temperatures from lack of sufficient woody streamside cover.
2. Excessive sediment in the channel from bank and upland erosion.
3. High coliform bacteria counts from upper watershed sources.
4. Channel widening from hoof-caused bank sloughing and later erosion by water.
5. Change in the form of the water column and the channel it flows in.
6. Change, reduction, or elimination of vegetation.
7. Elimination of riparian areas by channel degradation and lowering of the water table.
8. Gradual stream channel trenching or braiding depending on soils and substrate composition with concurrent replacement of riparian vegetation with more xeric plant species.

Kauffman and Krueger (1984), in an extensive review of livestock impacts on riparian ecosystems, documented many factors interrelated with grazing effects, primarily dealing with instream ecology, terrestrial wildlife, and riparian vegetation. However, as with many others, the authors were not able to find much information other than that abusive grazing practices are damaging to many features of riparian ecosystems. Little information is available on how well-managed grazing affects riparian-stream systems. Criticisms of conventional grazing systems such as rest-rotation typically contain no information on actual grazing intensity or degree of plant utilization (Meehan and Platts 1978; Storch 1979).

Permanent removal of grazing will not guarantee maximum herbaceous plant production. Volland (1978) found that a protected Kentucky bluegrass meadow reached peak production in 6 years and then declined until production was similar to the adjacent area grazed season-long. Similar results were reported by Bryant (1988) and Green (1989) in northeastern Oregon. The accumulation of litter over a period of years seems to retard herbage production in wet meadow areas. Thus, some grazing of riparian areas could have beneficial effects. This is a response similar to that documented by Branson (1985).

Resistance of common riparian woody plants to defoliation has not been investigated. However, genera commonly represented in riparian areas such as dogwood, maple, cottonwood, willow, and birch appear to be more resistant to foliage and twig removal than genera common to xeric uplands. Light to moderate grazing generally appears to have little adverse effect and in some cases may stimulate growth (Skovlin 1984). Severe overgrazing almost invariably is detrimental to willow communities (Kauffman and Krueger 1984). Knopf and Cannon (1982) reported that cattle altered the structure of a high-altitude willow community by changing the size, shape, volume, and quantity of live and dead stems per bush, and the spacing of plants. They concluded that 10 to 12 years was not sufficient time for a riparian willow community to recover from a history of excessive grazing. Alternatively, Skovlin (1984) reported that reestablishment of acceptable wildlife habitat often occurred about 5 years after release of remnant shrubs from heavy grazing. Little information is available on how careful grazing affects willow communities except for observations that leaving a residual herbaceous stubble of about 4 inches usually results in little or no use of willows (see "Utilization" section in this appendix).

While Skovlin (1984) suggested that vegetation recovery after release from excessive grazing generally can occur within 5 to 15 years, Platts and Raleigh (1984) pointed out that impacts on fishery environments go far beyond the riparian vegetation. Channel and bank morphology, instream cover, and water flow regimens are important factors. Little is known about the recovery time for these factors in different environments. Skovlin suggested that sediment delivery to the stream was the most detrimental impact of trampling to fisheries. Platts and Raleigh, however, pointed out that the retention of bank morphology and stability are probably more important. The maintenance of streambank structure and function is a key item

in riparian-stream habitats from both fisheries and hydrologic standpoints (Bohn 1986; Platts 1983).

Vegetation plays a dominant role not only in the erosional stability of streambanks but also in the rebuilding of degraded streambanks. Streamside vegetation serves as a natural trap to retain sediments during high flows. These sediments form the physical basis for new bank structure (Elmore and Beschta 1987).

Grazing Systems

An evaluation of the effects of rest-rotation grazing on streambanks was conducted on forested watersheds in Idaho (Platts and Nelson 1985). Forage in the streamside zone was used at a higher rate than on either immediately adjacent range or the grazing allotment. Relative use of streamside vegetation was less during the early grazing period than during the late grazing period. Small treatment pastures experienced 11 percent higher average use of streamside vegetation with late grazing than with early grazing. This was suggested to be the result of "a general tendency for cattle to avoid certain streamside zones early in the season when the soils and vegetation may be wet" (Platts and Nelson 1985). Also, the vegetation on adjacent rangeland was more succulent during the early growing season.

Platts (1989) provided an evaluation of several livestock grazing systems based on his own observations. He identified, described, and evaluated 17 grazing "strategies" on a scale of 1 to 10. All strategies that were described as having use levels of heavy or heavy to moderate were rated on the lower half of the scale (1 to 5). Those strategies that incorporated moderate or moderate to light use rated in the mid-upper portion of the scale (6 to 8). Those management strategies that featured light or no use were rated at the top of the scale (9 to 10). Although the strategies, use levels, and ratings described above are largely qualitative in nature, they do provide support for the opinions of several other authors (Van Poollen and Lacey 1979; Skovlin 1984) in that use levels seem to be the most important factor in a grazing situation.

In a test of different grazing systems at Meadow Creek, Starkey Experimental Forest and Range, deferred-rotation, rest-rotation, and season-long grazing all resulted in increases in production of floodplain herbage when utilization at the end of the grazing period was 70 percent or less. Likewise, each of these grazing systems produced almost twice as much herbage as ungrazed plots after 6 years (Bryant 1985). Bryant (1988) concluded that probably any grazing system, even season-long, would be acceptable for floodplains if use was controlled. However, Bryant made no grazing study of the streamside vegetation.

Other studies have also shown little net benefit from specific grazing approaches. Gillen and other (1985) showed that the same residual standing crop of herbage was present on dry meadows under both continuous and deferred-rotation grazing systems. Marlow and others (1989) found little difference in streambank stability among four grazing strategies studied during three drought years. Platts and Raleigh (1984) quoted Myers' (1981) results as showing no correlation between riparian condition and type of grazing system used. The grazing intensity was an important factor in the resulting riparian condition but not as important as amount of vegetation used during the hot season of the year. Vegetation did not respond when defoliated during that period.

As more studies of grazing systems are completed, it appears that the complex array of factors in rangelands tends to buffer the theoretical benefits of many systems. This has been true in a number of comparisons of upland grazing, and experience in riparian areas has generally failed to show an advantage to any specific grazing system.

Utilization

Few guidelines are available on what the allowable use of riparian plant communities should be to maintain ecosystem integrity. Allowable use could be described in terms of percentage of weight removed, residual biomass, or residual stubble height. Ratliff and others (1987) suggested that for site protection the herbage remaining after grazing should equal the proportion of production that decomposes annually. This translated into utilization rates of 35 to 45 percent on excellent-condition meadows down to 20 to 30 percent on poor-condition meadows. Platts (1982) suggested that rest-rotation grazing with 65 percent use or higher resulted in altered riparian habitat conditions while 25 percent use or less had little effect. Based on studies at Meadow Creek, Bryant (1985, 1988) thought that use of floodplain herbage could be up to 70 percent regardless of grazing system if about 3 inches of forage stubble height remained. Similar opinions on stubble height were given by Krueger (1989). Kauffman and others (1983) report observations by F. C. Hall that a shift to shrub use does not generally occur (except in the case of highly palatable shrubs) if 4 inches of herbaceous stubble remains. Elmore (1988) suggested that 3 to 4 inches of stubble height would maintain plant vigor, provide streambank protection, and aid deposition of sediments to rebuild degraded streambanks. Elmore also suggested that in some situations the use on willows begins when use on herbaceous plants reaches about 45 percent. An evaluation of 34 grazing systems in place for 10 to 20 years showed the importance of providing residual vegetation cover (Myers 1989). Vigorous woody plant growth and at least 6 inches of residual herbaceous plant height at the end of the growing/grazing season typified the riparian areas in excellent, good, or rapidly improving condition. This residual plant cover appeared to provide adequate streambank protection and sediment entrapment during high streamflow periods.

An approximate relationship between percentage utilization and stubble height of riparian graminoids was developed based on 1988 data from the Stanley Creek (mountain meadow ecosystem) and Pole Creek (sagebrush ecosystem) studies (Clary 1987b). The data suggest that

average utilization levels of 24 to 32 percent were obtained when riparian graminoids were grazed to a 6-inch stubble height, that average use levels of 37 to 44 percent were obtained when grazing to a 4-inch stubble height, and that average use levels of 47 to 51 percent were obtained when grazing to a 3-inch stubble height (Clary 1988). This relationship shows some continuity between recommendations of 40 to 50 percent utilization and recommendations of leaving 3 to 4 inches of residual stubble height for maintenance of plant vigor. However, additional stubble height, such as 6 inches or more, may be necessary to protect riparian ecosystem function (Myers 1989).

Season of Use

Seasonal distribution of use often varies from heavy riparian area use in the summer to little riparian area use in winter (Goodman and others 1989). Myers (1989) reported that livestock are much less likely to disperse across a large grazing unit during the hot portion of the growing season than in the spring, particularly if the upland vegetation has ceased growth. The resulting summer concentration of use in the riparian zone becomes a key factor in severity of trampling and mechanical damage, soil compaction, and plant utilization.

Kauffman and others (1982) suggested late-season grazing for riparian zones on the basis of livestock production, maintenance of plant vigor and production, and minimum disturbance of wildlife populations. Clipping studies by Pond (1961) showed a similar response by the plant community. Results in southwestern Montana suggested that streambanks were most stable when grazed in late summer (Marlow and others 1987). Others, however, feel that fall grazing is not necessarily the optimum on many sites (Kinch 1987). A fall-grazed plant community, particularly a heavily grazed plant community, has a reduced ability to protect existing banks and to trap new sediments as part of the streambank building process. Although late season grazing may be a good approach from the standpoint of some plant communities and some terrestrial wildlife situations, spring grazing may be preferred in many situations to maintain proper streambank structure and function (Elmore and Beschta 1987).

A promising approach is to graze riparian areas in the spring, then remove all livestock and allow forage plants to regrow for the remainder of the season. This should provide vegetation cover for streambank protection during the following winter and early spring high streamflow periods. Several of the riparian grazing examples given by Elmore (1988) showed substantial improvements when grazed in spring only. Crouse (1987) reported beneficial results from spring grazing. Platts and Nelson (1985) recorded less severe use of streambanks in the spring than occurred in the fall relative to the surrounding uplands. Cattle use was more evenly distributed in the spring and therefore not as concentrated in the riparian zone. In Wyoming, relatively intense short-term spring grazing appeared to have no adverse effect on channel morphology of an ephemeral stream, while changes did occur during summer grazing (Siekert and others 1985). Animal sightings in the riparian zone and use of riparian species in the spring were less than half those occurring later in the season. In Oregon cattle avoid many riparian areas until late summer because of wet soil conditions. Thus, little grazing occurs during spring-only grazing strategies (Kovalchic 1987).

In a mountain meadow on Stanley Creek in Idaho, grazing in late June and early July resulted in slightly less use of streamside areas than the adjacent dry meadows (Clary 1988). This apparently occurred in part because of level topography and because the succulence (moisture content) of the herbage was similar between streamside vegetation and adjacent "dry" meadows in early summer. A similar distribution of use between streamside vegetation and dry meadows occurred in the fall after heavy frosts had "browned off" all vegetation.

In a study on Pole Creek in eastern Oregon, the natural regeneration of willows, cottonwoods, and other woody riparian shrubs was monitored in the protected, moderate spring-grazed, moderate fall-grazed, and heavy season-long pastures (Shaw 1988). Although topographic variability among pastures and heavy year-around browsing by deer complicated evaluations, two trends seemed apparent after two growing seasons: (1) total seedling density of willows and cottonwoods in the heavy use season-long pastures was less than a fourth that of any other treatment, and (2) willow and cottonwood seedling densities were somewhat greater in the spring-grazed pastures than any of the other treatments.

APPENDIX III: CALCULATING ECOLOGICAL STATUS AND RESOURCE VALUE RATINGS IN RIPARIAN AREAS

A. H. Winward

Regional Ecologist, Intermountain Region, Forest Service, U.S. Department of Agriculture, Ogden, UT

Ecological Status

Ecological status is used to relate the degree of similarity between current vegetation and potential vegetation for a site. It can be measured on the basis of species composition within a particular community type or on the basis of community type composition within a riparian complex. The categories for ecological status include: early seral, mid seral, late seral, and potential natural community(ies) (PNC) based on the degree of similarity to the potential natural community. Similarity between the present vegetation and the PNC can be calculated by a coefficient of similarity ($2w/a+b$) where a is the sum of species values for measured factors of present vegetation, b is the sum of values in the PNC, and w is the sum of the values common to both (table 1) (Range Inventory Standardization Committee 1983).

Composition values for the species or PNC's must be obtained by sampling sites in as natural a condition as possible. If no representative undisturbed areas are available, extrapolation of composition from ecological settings approximating the PNC may be necessary. Only those species or community types known to be native to a particular ecological setting may be used for establishing PNC values. Tables 2 and 3 provide examples of several ecological status ratings in different riparian settings using community type composition values.

Table 1—Example of ecological status of vegetation using coefficient of community similarity on foliar cover data

Species	Potential natural community	Present community	Amount in common
	- - - - - -	*Percent*	- - - - - -
Booth willow	65	30	30
Water sedge	5	2	2
Beaked sedge	85	35	35
Kentucky bluegrass	0	53	0
Solomon-seal	5	0	0
	a=160	b=120	w=67

Similarity to PNC	Ecological status
Percent	
0-25	Early seral
26-50	Mid seral
51-75	Late seral
76+	PNC

Therefore, similarity index of (2*67/160+120) = 48 percent or mid seral status

Table 2—Example of an ecological status rating in the mountain alder/dogwood-steep gradient riparian complex (Rosgen channel A) using community type composition values

Community type	Potential natural composition	Present composition	Amount in common
	- - - - - -	*Percent*	- - - - - -
Alder/dogwood	65	50	50
Booth willow/dogwood	5	5	5
Booth willow/horsetail	5	5	5
Booth willow/bluejoint reedgrass	5	5	5
Booth willow/mesic grass	5	2	2
Wooly sedge	10	5	5
Winged sedge	5	0	0
Kentucky bluegrass/redtop	0	28	0
	a=100	b=100	w=72

Therefore, similarity index of (2*72/100+100) = 72 percent or late seral status

Table 3—Example of an ecological status rating in the Nebraska sedge-low gradient riparian complex (Rosgen channel D) using community type composition values

Community type	Potential natural composition	Present composition	Amount in common
		Percent	
Coyote willow/bar	3	1	1
Nebraska sedge	85	10	10
Water sedge	5	2	2
Baltic rush	2	20	2
Mesic forb	3	10	3
Silver sagebrush/hairgrass	2	2	2
Kentucky bluegrass/redtop	0	55	0
	a=100	*b*=100	*w*=20

Therefore, similarity index of (2*20/100+100) = 20 percent or early seral status

Table 4—Examples of a resource value ratings (RVR) in the Booth willow/beaked sedge-moderate gradient riparian type (Rosgen channel C) using community type composition values

Community type	Desired composition	Present composition		Amount in common	
		Area A	Area B	Area A	Area B
			Percent		
Booth willow/beaked sedge	20	16	3	16	3
Wolfs willow/hairgrass	5	3	1	3	1
Water sedge	7	2	1	2	1
Beaked sedge	60	50	8	50	8
Baltic rush	3	10	10	3	3
Kentucky bluegrass	0	5	47	0	0
Mesic forb	3	13	30	3	3
False-hellebore	2	1	0	1	0
	a=100	*b*=100	*b*=100	*w*=78	*w*=19

Similarity to desired *Percent*	Resource value rating (RVR)
0-25	Poor
26-50	Fair
51-75	Good
76+	Excellent

Therefore, area A similarity index of (2*78/100+100) = 78 percent or excellent.
Therefore, area B similarity index of (2*19/100+100) = 19 percent or poor.

Or, alternatively, using a similarity criterion of >75 percent:

Area A similarity index of 78 percent = meeting management objectives;
Area B similarity index of 19 percent = not meeting management objectives.

Additional factors such as ground cover, soil compaction, streambank breakage, or channel form may be used to refine ecological status. These values will likewise be based on percentage of similarity to values obtained in an undisturbed setting.

Resource Value Ratings

We often choose to manage vegetation for some seral stage other than PNC. In these cases, another approach used to evaluate status or condition of riparian areas is to compare the present species or community type composition of an area to a desired set of species or community types capable of occurring in that area (Winward 1989). On public lands, the "desired values" are developed by professionals in an interdiscipinary setting. Similarity values between "present" and "desired" are calculated using a process similar to that used in developing ecological status ratings. Categories for rating the site are poor, fair, good, and excellent as in past range condition ratings (table 4). Or, categories can be developed to determine whether the site is or is not meeting management objectives. Information from the Range Inventory Standardization Committee Report (1983) suggested that a value of 75 percent similarity or greater may be used to differentiate between meeting and not meeting management objectives.

Clary, Warren P.; Webster, Bert F. 1989. Managing grazing of riparian areas in the Intermountain Region. Gen. Tech. Rep. INT-263. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 11 p.

Concern about livestock grazing in riparian habitats and its effect upon riparian-dependent resources has resulted in numerous controversies about the appropriate management approach. This document provides guidance for grazing of riparian areas in a manner that should reduce both nonpoint source pollution and potential grazing impacts on other riparian-dependent resources.

KEYWORDS: nonpoint source pollution, utilization, stubble height, grazing systems, streambanks

INTERMOUNTAIN RESEARCH STATION

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Reduction of Soil Erosion on Forest Roads

Edward R. Burroughs, Jr.
John G. King

THE AUTHORS

EDWARD R. BURROUGHS, JR., is a research engineer and leader of the engineering technology project for improved resource management, Intermountain Research Station, Forestry Sciences Laboratory, Moscow, ID.

JOHN G. KING is a hydrologist in a research project to minimize nonpoint source pollution in the Northern Rocky Mountains, Intermountain Research Station, Forestry Sciences Laboratory, Boise, ID.

RESEARCH SUMMARY

Results of onsite erosion control work from across the United States provide estimates of the amount of erosion reduction on forest roads from various treatments. Supplementary information includes the effects of slope gradient, soil characteristics, and ground cover. Estimates of sediment travel below fillslopes can be made, together with the combined effect of erosion control treatments of the running surface, road cut, and ditch.

CONTENTS

Front cover photo: Researchers use simulated rainfall to measure sediment production from road surfaces, cutslopes, and fillslopes.

Intermountain Research Station
324 25th Street
Ogden, UT 84401

Reduction of Soil Erosion on Forest Roads

Edward R. Burroughs, Jr.
John G. King

INTRODUCTION

Estimates on erosion reduction were obtained from selected treatments applied to such forest road components as traveledway, cutslope, fillslope, and ditch. Data from the literature and from in-house research reports provide better insight into effective treatments to reduce erosion. These results should have application to revisions of the "Guide for Predicting Sediment Yields from Forested Watersheds" (Cline and others 1981) developed for the Forest Service's Northern and Intermountain Regions. This guide was originally designed as a method to estimate increases in sediment production from watersheds as the result of various land management practices.

The current Sediment Guide for the Northern (R-1) and Intermountain (R-4) Regions allows a percentage reduction in sediment yield from the total road prism as the result of applying a single erosion control practice, or the application of a combination of practices (Cline and others 1981, table 4). These reductions in onsite sediment production from the total road imply a partitioning of total sediment production of about 60 percent from fillslopes, 25 percent from traveledways, and 15 percent from the cutslope and ditch. This partitioning was discovered by comparing erosion reduction factors in the guide with the amount of erosion reduction for individual road prism components as given in the literature cited in the guide's table 4. New information about onsite road sediment is based on studies by the Intermountain Research Station's Engineering Technology and Watershed Management Research Work Units. These studies show that partitioning of sediment production may be significantly different from that used in the guide and can change as a mitigation measure applied to one road prism component influences sediment yield from other components. This report discusses the potential for reduction of onsite sediment production by various treatments on each component of the road prism.

MITIGATION OF EROSION

Based on our research and the literature, we have compiled a comprehensive study of the mitigation of erosion from specific components of the road prism: traveledways, fillslopes, cutslopes, and roadside ditches. Because the sediment yields from adjacent components are not directly additive, we need also to review studies on combined erosion control for these areas.

Traveledways

Data on erosion reduction from treated traveledways come from two types of experiments: (1) natural rainstorms and snowmelt on road segments defined by cross drains or dips and (2) simulated rainfall on bordered road segments or small bordered plots. A study of sediment production from treated and untreated road segments subject to natural climatic events was completed by Swift (1984b) in North Carolina. Sediment production in tons per acre per inch of precipitation was measured for bare traveledways before and during timber harvest and also for graveled traveledways subject to light vehicle traffic. These data show that logging traffic on an unsurfaced traveledway can increase sediment production by a factor of 1.90. Our measurements of sediment production from an unsurfaced traveledway in border-zone batholith material with simulated rainfall showed that a surface rutted by a heavy truck will produce 2.08 times the yield of a smooth surface (Burroughs and others 1984). We recommend that the estimated sediment production for a rutted, unsurfaced traveledway be increased by a factor of 2, relative to the yield from a smooth, unsurfaced traveledway.

Swift's (1984b) study further showed that placement of a 6-inch lift of 1.5-inch minus crushed rock reduced sediment production by 70 percent from the unsurfaced condition over a 5-month period. The gravel achieved this amount of protection even though this period included 6.46 inches of rainfall in 5 days. In 13.3 months, the gravel with established grass at the margins of the traveledway reduced sediment production by over 84 percent compared to 9.5 months when the road was unsurfaced.

Simulated rainfall was applied to two 100-ft bordered sections of the Rainy Day road, Nez Perce National Forest, built in "border-zone batholith" material of gneiss and schist (Burroughs and others 1985a). One section was left unsurfaced and the other was surfaced with a 4-inch lift of 1.5-inch minus hard gneissic crushed rock. Each section was 13 ft wide with an 8 percent centerline grade and was insloped at 4.4 percent to a standard ditch. Total sediment for the first rainfall application on the gravel-surfaced road section was 64.3 lb from 1.05 inches of rainfall, or 61.2 lb per inch of rainfall. Total sediment from the first rainfall on the unsurfaced road section was 312.1 lb per 1.08 inches of rainfall, or 289.0 lb per inch of rainfall. The reduction in sediment production by graveling this road section was 79 percent, which compares well with Swift's (1984b) results for a section of road protected only by gravel.

Other data by Swift (1984a) show that the thickness of the gravel layer is important. Two inches of crushed rock (1.5 inch minus) placed on a road built in sandy loam soil showed no sediment reduction over the yield from an unprotected road. A 6-inch lift of crushed rock (1.5 inch minus) reduced sediment yield by about 92 percent, and an 8-inch layer of large stone (3.0-inch D_{50}) reduced sediment production by about 97 percent.

A similar study in West Virginia by Kochenderfer and Helvey (1987) tested roads surfaced with 6-inch lifts of 3-inch washed gravel (size ranged from 1.5 to 3 inches) and 3-inch crusher-run gravel. Average reductions in sediment production were 88 percent and 79 percent, respectively, over an unprotected road during the 4-year measurement period.

Mitigation of sediment production by graveling is a function of the erodibility of both the gravel and the underlying material. Erosion reduction by gravel surfacing is maximized by the use of hard crushed rock over highly erodible subgrade material.

Measurements of sediment production from surfaced and unsurfaced traveledways were made using simulated rainfall on bounded segments of forest roads (Burroughs and others 1983a; Burroughs and King 1985b). Sediment production was measured on three segments of an unsurfaced road built in granitic materials in Silver Creek, ID, and are compared to two road segments surfaced with dust oil and bituminous surface treatment. Dust oil and the bituminous surface treatment reduced sediment production by 85.3 percent and 96.6 percent, respectively (Burroughs and others 1983a) compared to sediment production from unsurfaced roads. There are drawbacks to each of these treatments: dust oil releases volatile chemicals into surface runoff and the surface breaks down easily under heavy traffic; and bituminous surface treatment is expensive. No good data were found on sediment reduction by lime or magnesium chloride.

Fillslopes

The success in minimizing fillslope surface erosion will depend on the timing of application of any control measure, the type of treatment, the rate of application for mulch treatments, the inherent erodibility of the soil, the slope gradient, and whether or not the road is insloped. This section discusses the effectiveness of various treatments for controling surface erosion on new fillslopes.

Most studies that have measured sediment production from fillslopes over time show that, initially, rates in this unconsolidated material are high and exponentially decrease over time (Megahan 1974; King 1984). For example, figure 1 illustrates the cumulative fillslope sediment production for the first summer and fall following construction of 1.5 miles of road in the Horse Creek watersheds of northern Idaho. This road was completed and sediment production measurements were initiated in mid-August 1978. The fillslopes were hydromulched, seeded, and fertilized in mid-September. During the first 30 days, about 3 inches of rain fell, which included 5 days with amounts greater than 0.3 inches. This was an unusually high rainfall for this period. The average amount of rainfall expected during 30 days in August and September is slightly less than 2 inches. The single largest event was a 0.89-inch thunderstorm that occurred 5 days after the beginning of measurements. Initially, fillslope sediment production was responsive to rainfall, partially because of the absence of mulch and the availability of easily eroded particles on the unconsolidated fillslopes. About half of the total fillslope sediment production measured over a 2-year period took place in the first summer and fall. Thus, erosion control measures that can be put in place immediately after fillslope construction have a much larger potential to appreciably reduce sediment production compared to measures that are implemented later.

If treatment is delayed following road completion, we suggest that the percentage of erosion reduction be decreased. The time delay in treatment, expected precipitation, and armoring effects should all be considered in estimating a weighted sediment reduction percentage.

We analyzed published data and in-house research results to determine how selected erosion control treatments compared and how their effectiveness was influenced by soil characteristics, slope gradient, and ground cover. We identified six treatments: (1) straw with asphalt tack, (2) straw with a net or mat, (3) straw alone, (4) erosion control mats, (5) wood chips or rock, and (6) hydromulch. Figures 2 through 8 illustrate the increasing effectiveness of each treatment with increasing ground cover. Of lesser importance in these data sets was silt content of the underlying soil and slope gradient. Generally, the steeper the slope and the siltier the soil, the less effective the treatment. The importance of ground cover in reducing surface erosion for any treatment is apparent in the similar shape of curves in figures 2 through 6. A curve to estimate the application rate for some treatments is also given. For example, to achieve an 80 percent reduction in erosion, estimate the required ground cover from the main curve, then estimate the application rate to attain that ground cover from the application rate curve. For straw mulch alone, an 80 percent erosion reduction would require 96 percent ground cover (fig. 4a), or about 2.9 tons per acre (fig. 4b).

The estimated amount of reduction in sediment can only be achieved on smooth slopes with proper installation and anchoring of the material, especially for mats and nets. Rocks, slope irregularities, or gullies prevent good contact between the slope and the material and reduce their effectiveness. The effectiveness of any mulch may be reduced where frequent frost heave or ground ice occurs.

The curve for hydromulch shown in figure 7 does not show the same relationship between cover and sediment reduction as the other treatments. Because it has short fiber lengths, it is easily detached and transported off the steeper slopes by surface runoff, unless some fiber tackifier is used. Dudeck and others (1967) compared the application of wood cellulose fibers (1,000 lb per acre) alone and with an asphalt emulsion (150 gal per acre of 1:5 emulsion) and reported about a 35 percent decrease in relative erosion using the emulsion.

Figure 8 shows all six treatments plotted on the same graph to better compare their effectiveness.

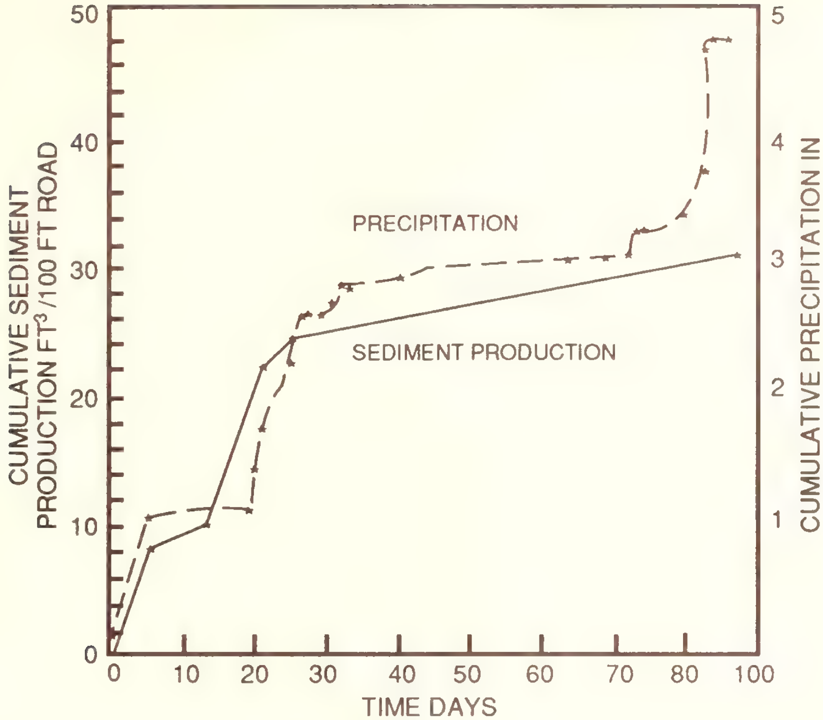

Figure 1—Cumulative fillslope sediment production from rainfall.

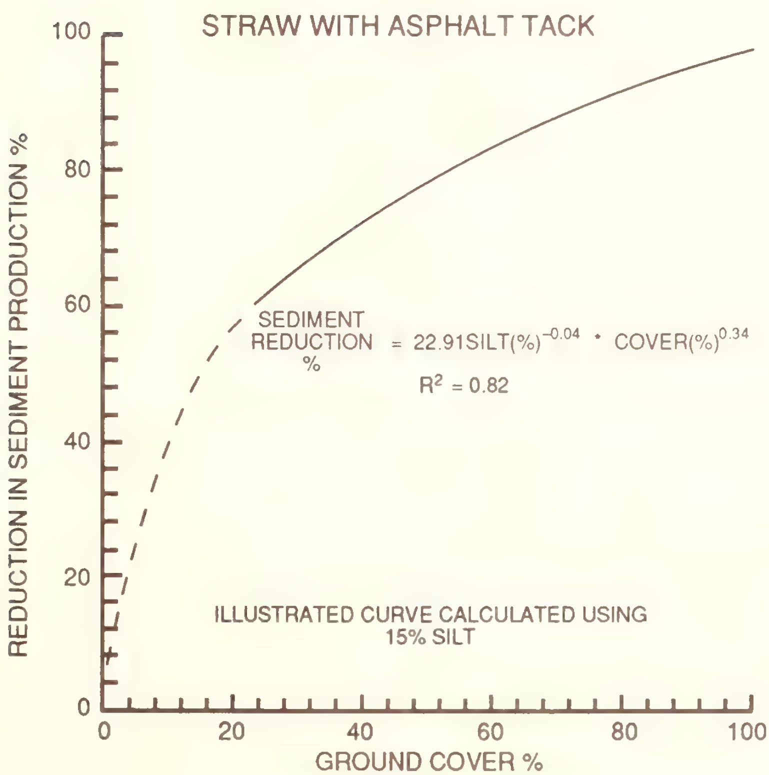

Figure 2—Erosion reduction provided by straw with an asphalt tack (Barnett and others 1967; Dudeck and others 1967; Kay 1984).

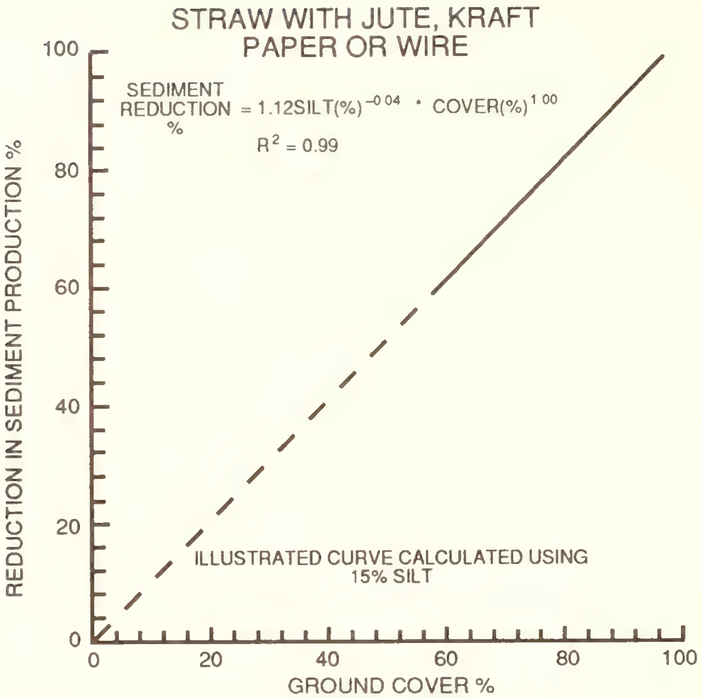

Figure 3—Erosion reduction provided by straw with a net or mat (Bethlahmy and Kidd 1966; Dudeck and others 1967).

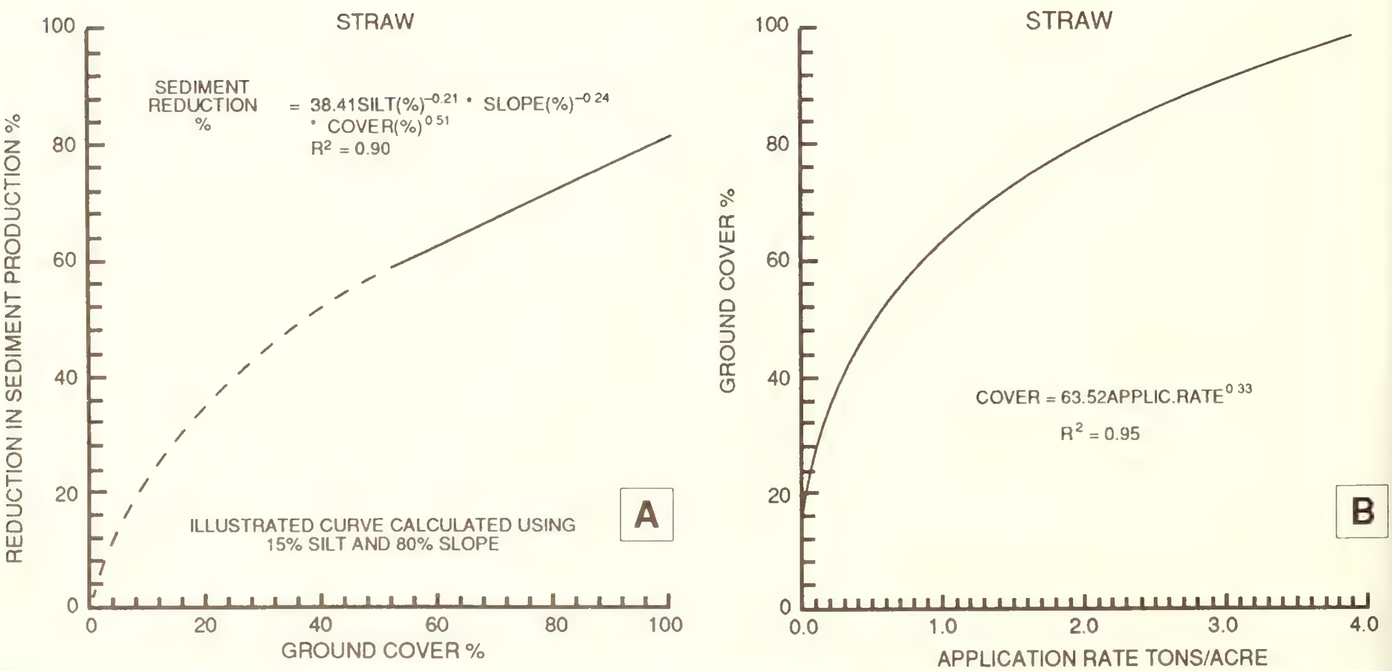

Figure 4—(A) Erosion reduction provided by straw. (B) Ground cover provided by application rate for all straw treatment. (Barnett and others 1967; Meyer and others 1970; Kay 1984.)

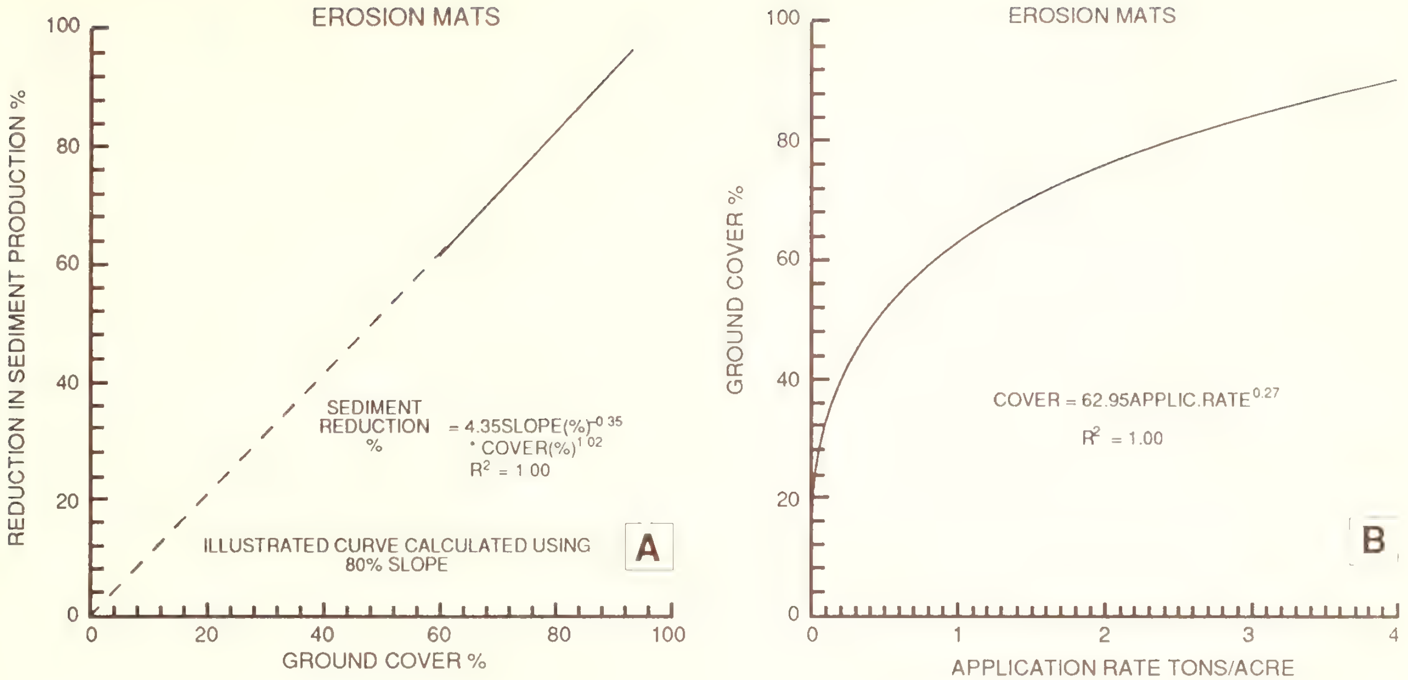

Figure 5—(A) Erosion reduction provided by mats. (B) Ground cover provided by application rate for erosion mats. (Dudeck and others 1967; Gulf Corp. 1977; Kay 1984; Burroughs and King 1985; Burroughs and others 1985.)

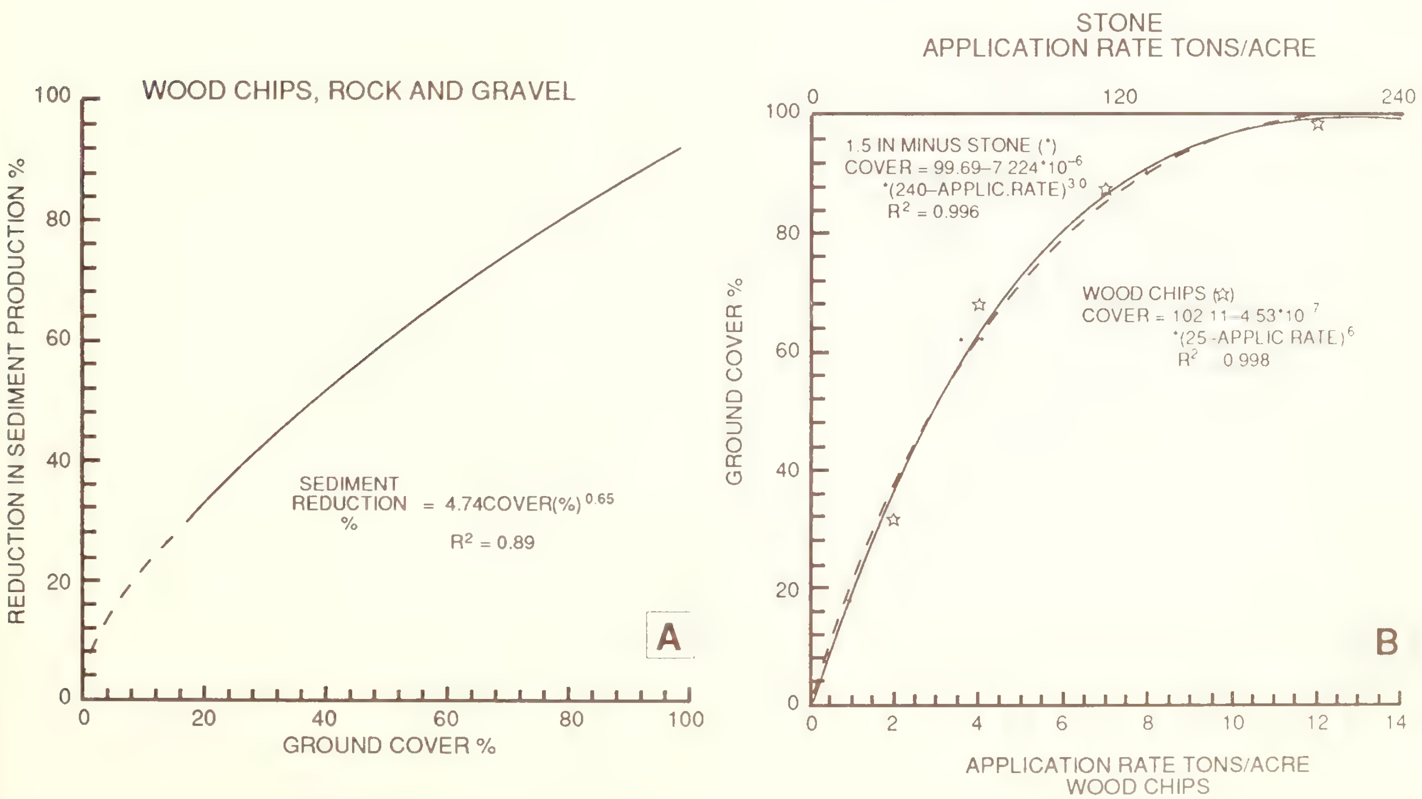

Figure 6—(A) Erosion reduction provided by wood chip or rock mulches. (B) Ground cover provided by application rates for two mulches. (Meyer and others 1972.)

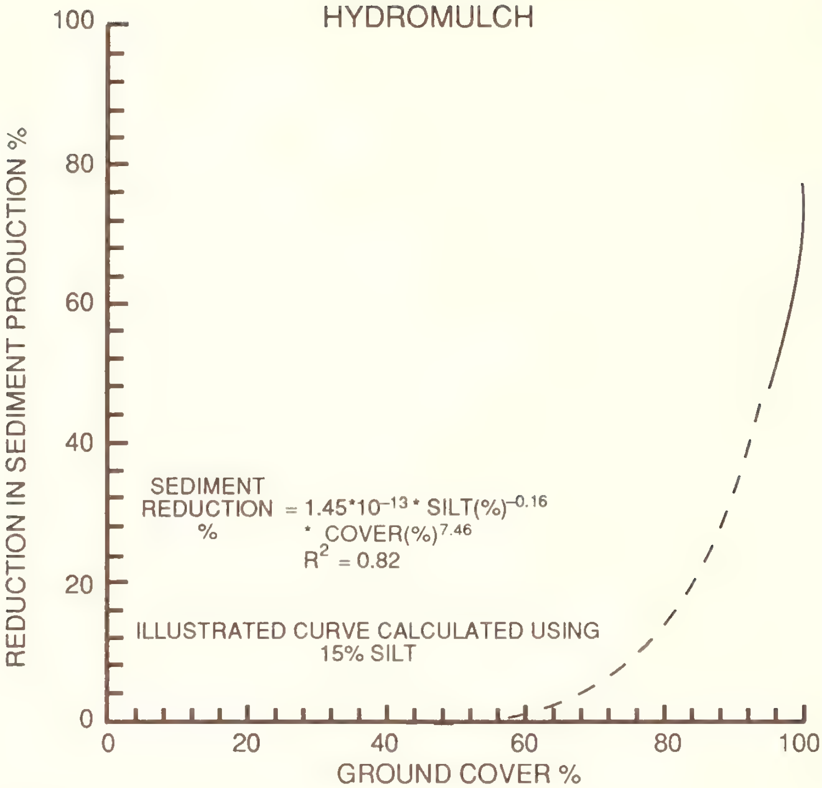

Figure 7—Erosion reduction provided by hydromulch (Dudeck and others 1967; Kay 1984).

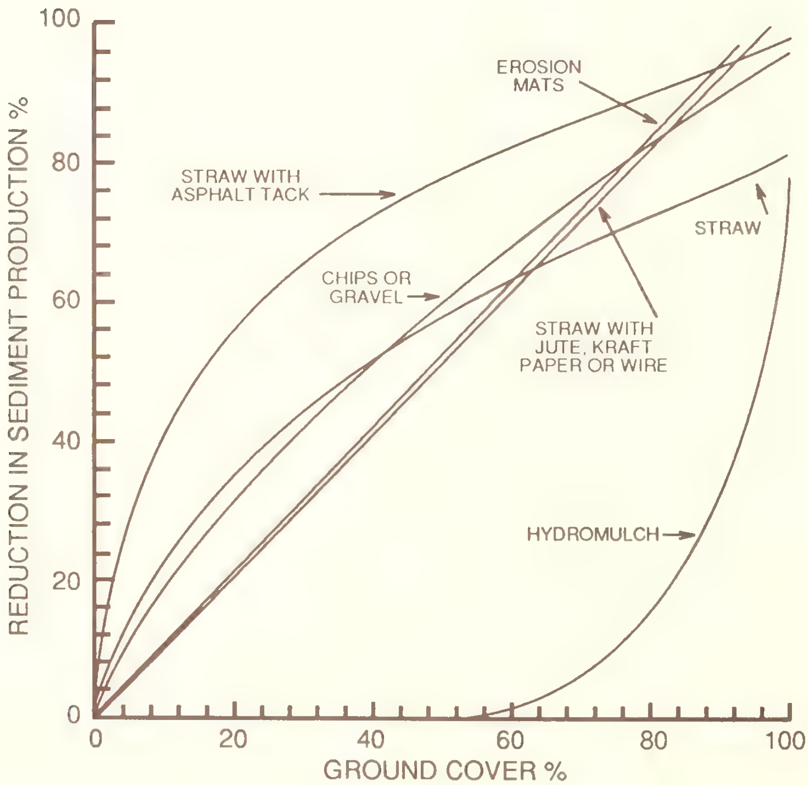

Figure 8—A comparison of erosion reduction provided by selected treatments for average site conditions.

The effectiveness of any mulch treatment can be reduced if traveledway drainage contributes to the fillslope, promoting accelerated rill and gully erosion. Fillslope sediment production was measured with unbordered plots below crowned traveledways at Horse Creek in northern Idaho (King 1979, 1984). Almost all of the larger gullies in the fillslope were generated from traveledway drainage. This process was more dominant than any sheet or splash erosion process. On fillslopes with a vertical height of less than 20 ft, reductions due to seed, hydromulch (1,500 lb per acre), or straw mulch (2 tons per acre) with an asphalt tackifier (250 gal per acre) were statistically similar and ranged from 46 to 58 percent over a 3-year period. The treatment effects were also statistically similar on fills with vertical heights of 20 to 40 ft, resulting in only a 24 to 30 percent reduction. For the straw mulch with an asphalt tackifier, the reductions were much smaller than expected because the mulch was not able to protect the fills from concentrated drainage from the traveledway.

Seeding alone does little to control surface erosion until germination and growth of the new plants, and then only if the seed has not been washed from the slope. Bethlahmy and Kidd (1966) report no sediment reduction from dry seeded and furrowed, steep 1.25:1 decomposed granitic fills in Idaho. In North Carolina, Swift (1984b) collected fillslope sediment data for 9.5 months following road construction and logging, during which the fills were not seeded. These data were compared with the sediment collected during the first 5 and 13.3 months following seeding to show average reductions of 7 and 58 percent, respectively, for these periods as grass became established on the fillslopes.

Wollum (1962) reported results from seeding and fertilizing a 1.25:1 slope on layered tuffs and breccias in western Oregon. Comparison of sediment measured over 1 year from a 6-year-old bare slope to the erosion from the first year after seeding indicates about a 68 percent reduction. In both these studies the comparison is between preseeded and postseeded erosion for the same slope with no separate control slope measurements. Erosion immediately after construction is usually high and diminishes over time as the easily dislodged material is eroded. Thus, the 68 percent (Wollum) and 58 percent (Swift) reductions in sediment are probably too high because of the surface armoring that occurred during the preseeded interval.

Rolling fillslopes was evaluated on the Silver Creek roads for layer-placed, sidecast, and controlled compaction construction. A decrease in the infiltration capacity of the slopes due to compaction by rolling probably generated more surface runoff and subsequently more sediment. Average increases in sediment, compared to nonrolled slopes, ranged from 107 to 532 percent with an average increase for the 11 plots of 282 percent (Boise State University 1984).

Also evaluated on the Silver Creek road fills was an application of a polymer soil binder. The binder initially formed a surface crust, which was broken by frost action and desiccation. Based on data collected by Boise State University (1984), average sediment production from the four polymer-treated plots was about twice that of the control plots. Because the crust prevents any infiltration, surface runoff is increased and erosion begins in any cracks in the crust. Kay (1984) reports that these crusts will not survive frost heaving nor will uncured crusts survive freezing temperatures.

Filter windrows are barriers constructed of logging slash that slow the velocity of any surface runoff, causing deposition of most sediments. They can be constructed on or immediately below the fillslope. The advantage of this treatment is that it can be constructed concurrent with road construction to provide immediate control of fillslope sediment. Filter windrow construction by hydraulic excavator (backhoe) is a cost-effective method to incorporate erosion control into forest road construction. Field evaluation of seven machine-constructed windrows in the Horse Creek watersheds over a 3-year period indicated a 75 to 85 percent reduction in sediment leaving the fillslope compared to adjacent hydromulched slopes (Cook and King 1983). We used data from simulated rainfall on bounded fillslope plots in northern Idaho (Burroughs and others 1985b) to estimate the effectiveness of various erosion control treatments used singly and in combination. Figure 9 shows a sediment reduction of about 88 percent by a hand-constructed filter windrow (same specifications as machine-constructed) for the first rainfall. The Curlex mulch is more effective than the filter windrow, but more expensive to apply. For particularly sensitive sites, such as forest roads above streams with high values for water quality, the combination of a filter windrow with Curlex mulch provides about 99 percent sediment reduction. In North Carolina, Swift (1985) evaluated "brush barriers" in terms of sediment travel distance below fillslopes and the frequency of sediment flows. He found that both the average and maximum sediment travel distances were about half as long below brush barriers as below fillslopes without the barriers, and the number of sediment flows per 1,000 ft of road were reduced by about 35 percent.

Rothwell (1983) used logging debris placed parallel to the contour and spaced 60 to 120 cm apart on road shoulders, ditches, and cutslopes at three stream crossings. Measurements of total suspended sediment production above and below the road at these three crossings and three control crossings indicated about a 75 percent decrease in storm sediment production as the result of debris barriers.

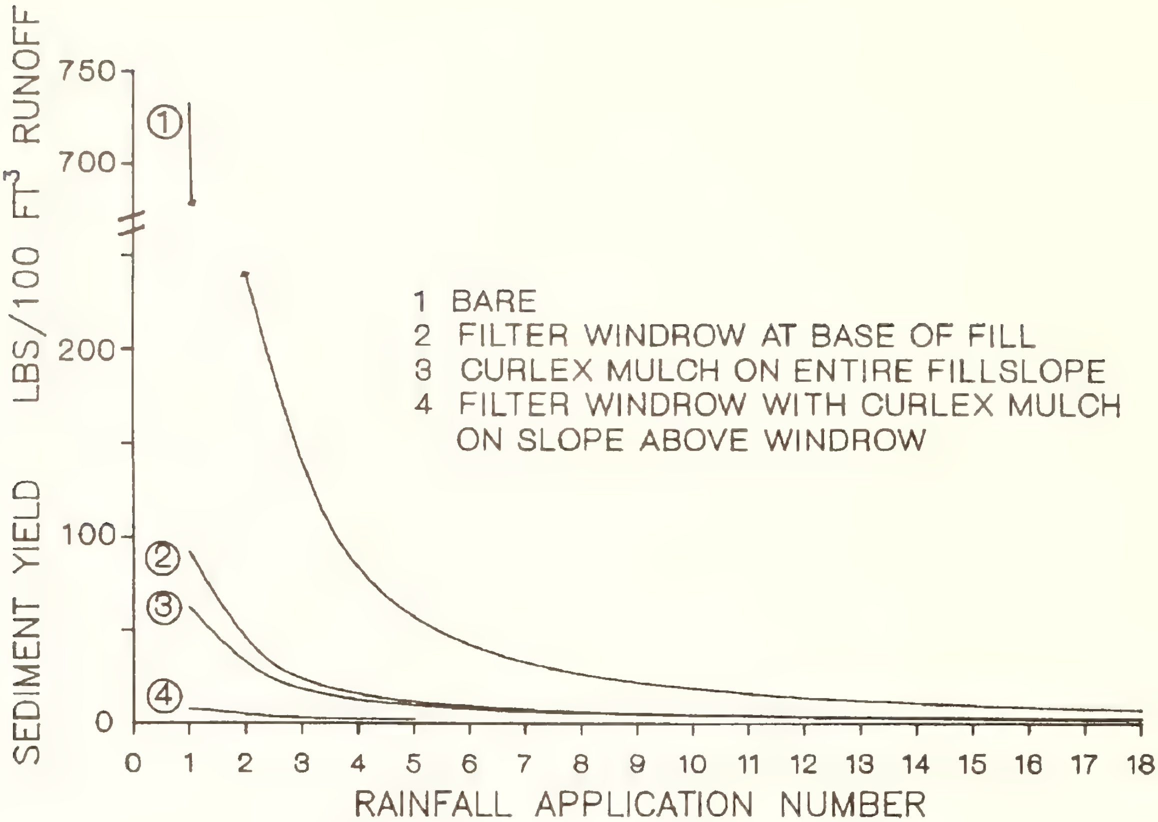

Figure 9—Reductions in sediment production as the result of selected erosion control treatments and surface armoring.

Travel Distances Below Fillslopes

Although the initial rate of fillslope erosion can be high compared to erosion rates on other road components, it is the transport of eroded material below the fillslopes that determines the degree that streams are affected by fill erosion. For most midslope forest roads, only those fillslopes near stream crossings have a high potential to contribute eroded material to streams. The slope distance required to prevent material from reaching a stream is a function of many interacting site and climatic factors, making it difficult to predict with any degree of accuracy. However, sediment transport distances below fillslopes at the Horse Creek and Gospel Hump sites in northern Idaho provide insight into relationships between transport distance and several site characteristics.

For 1.5 miles of road constructed in Horse Creek in 1978, rills and gullies formed in the fillslopes were inventoried and transport distances measured each spring and fall through the fall of 1980. Table 1 shows the average transport distances measured in the fall of 1980 for various categories of fillslopes. We excluded from this summary rills and gullies that contributed sediment to streams and rills that displaced less than 1 ft^3 of soil. The average transport distance below fillslopes with filter windrows of slash was about 4 ft. Typically, material was transported over the windrows in the spring when they were partially buried by the remaining snowpack rather than through the windrow. Of the 45 rills that formed in the windrowed fillslopes, only seven had sediment flows below the windrows. The maximum transport distance was 33 ft.

Those situations that resulted in the longest average transport distance were rills formed in slumped material and rills either below relief culvert outflows or rills whose flow paths combined with culvert flow paths. Respective average transport distances for these two situations were 80.4 and 72.8 ft.

Most common were rills formed in fillslopes that were not windrowed, had not slumped, and were not influenced by relief culvert flows. The transport distance was influenced by whether the traveledway contributed concentrated runoff to the fillslopes. Average transport distances were about 26 ft if not influenced by traveledway runoff and increased to about 59 ft for instances influenced by concentrated traveledway runoff. An obvious rill had to have formed in the subgrade above the fillslope rill before it was classified as influenced by traveledway runoff. Outsloping of the traveledway was not a classification criteria.

These data provide estimates of distances required between fillslopes and streams to minimize transport of fillslope-derived sediment to the streams. These data also illustrate the effectiveness of slash windrows in reducing

Table 1—Average transport distance of eroded fill material for Horse Creek road 9704

Category	Average transport distance	Maximum transport distance	Number of rills
	Ft		
Windrowed fillslopes	3.8	33	45
Nonwindrowed, no traveledway drainage, nonslumped, does not combine with culvert flows	25.8	86	112
Nonwindrowed, with traveledway drainage, nonslumped, does not combine with culvert flows	58.8	85	25
Nonwindrowed, slumped and nonslumped, combined with culvert flow paths	72.8	125	25
Nonwindrowed, formed in slumped material, not combined with culvert flow paths	80.4	106	30

transport distances and the importance of preventing concentrated traveledway runoff from being diverted onto fillslopes.

The Gospel Hump sites are on 25 road sections on the Nez Perce National Forest of Idaho (Carlton and others 1982). Rill and gully transport distances were measured along a 200-ft road segment at each site the second fall following construction. Additional measurements included the volume of eroded material in each rill, the slope of the fill and the forest floor, the length and height of the fill, the bulk density and particle size distribution of the fill material, the portion of the traveledway that contributed runoff to the fill, and an estimate of obstructions on the forest floor below the road. Obstruction density was a qualitative index from 0 to 6 with 6 representing the highest density of obstructions, such as slash, shrubs, and depressions. The reported linear regression model for estimating transport distance using many of these variables explained only 36 percent of the variation in the data. Although this variation is quite large, several important factors become apparent when the transport distance data are averaged for different obstruction index values and traveledway contributions (fig. 10). As the obstruction index below the fillslopes increases, the average transport distance decreases considerably. This relationship is an oversimplification because gully size may also influence sediment transport distance. Average transport distance was also affected by contributions of drainage from the traveledway. As shown in figure 10, in most instances traveledway drainage to the fills results in longer sediment transport distances.

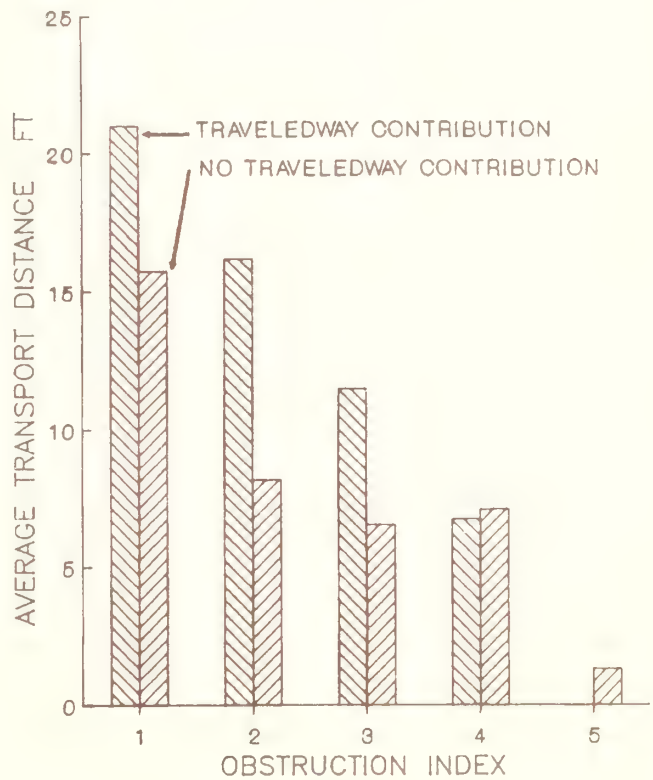

Figure 10—Sediment transport distance below road fillslopes as influenced by obstructions to trap sediment.

The cumulative frequency of sediment transport distance for the Horse Creek roads are shown in figure 11. Only transport data from Horse Creek fills that were not windrowed, not slumped, and did not combine with culvert flow paths were used for this comparison. Although the range of sediment transport distances remains similar, traveledway runoff shifts the cumulative curve toward the longer distances. For example, less than 10 percent of the rills not influenced by traveledway runoff had transport distances greater than 50 ft compared to about 70 percent of the rills that were influenced by runoff from the traveledway.

In the fall of 1980, transport distances were also measured for sediment flow paths below all relief culverts for the 7.2 miles of Horse Creek roads constructed in 1978 and 1979. Those sediment flow paths that reached streams were excluded from this analysis. At each relief culvert, additional measurements were made of contributing length(s) of road to the culvert and their corresponding centerline gradients and the gradient of the forest floor below the relief culvert along the sediment flow path. Transport distances were not strongly correlated to any of these variables (table 2).

The mean transport distance is not useful because the population of transport distances is skewed to extreme values. The cumulative frequency for sediment transport distance is more useful for planning. Figure 12 shows the predicted cumulative frequency for sediment transport distances. This curve was developed from the measured transport distances of sediment below 70 relief culverts. This relationship can be mathematically expressed as:

$$Y = 98.9048 - 9.9044\ 10^{-13} \cdot (625-X)^5$$
$$R^2 = 0.99$$

where

Y = cumulative frequency (percent)
X = transport distance (ft).

This relationship shows that for the Horse Creek roads, over half of the relief culverts had sediment transport distances exceeding about 75 ft. If the objective is to prevent 80 percent of the relief culverts from contributing sediment to streams, a distance of at least 175 ft must be provided between the culvert outfall and the nearest live water. This relationship probably varies substantially from place to place. However, because of the scarcity of

Table 2—Averages and ranges of data for sediment transport distance below relief culverts along the Horse Creek roads, fall 1980, and selected site characteristics

	Weighted road gradient	Total road length	Forest floor slope	Transport distance
	Percent	*Ft*	*Percent*	*Ft*
Average	5.5	299	41	127
Range	0.3-10.8	40-770	5-73	0-639
Correlation coefficient	0.15	–0.15	0.08	

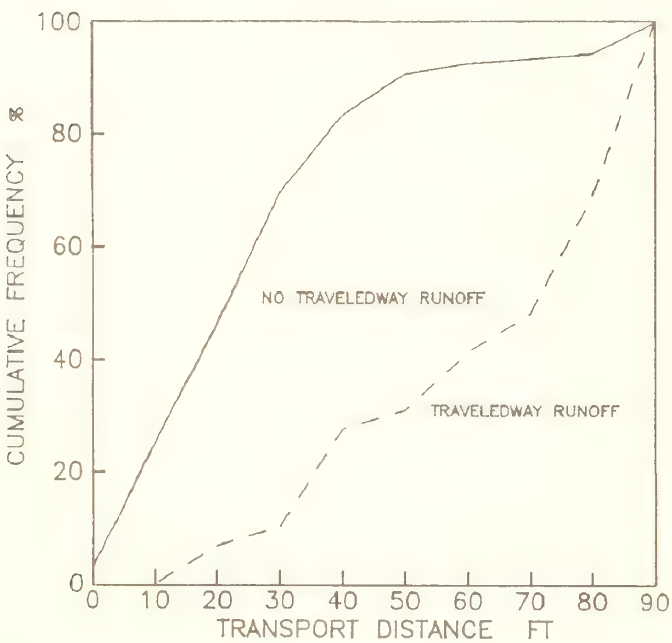

Figure 11—Cumulative frequency of sediment transport distances below fillslopes without the influence of slumps, filter windrows, or culvert outflow.

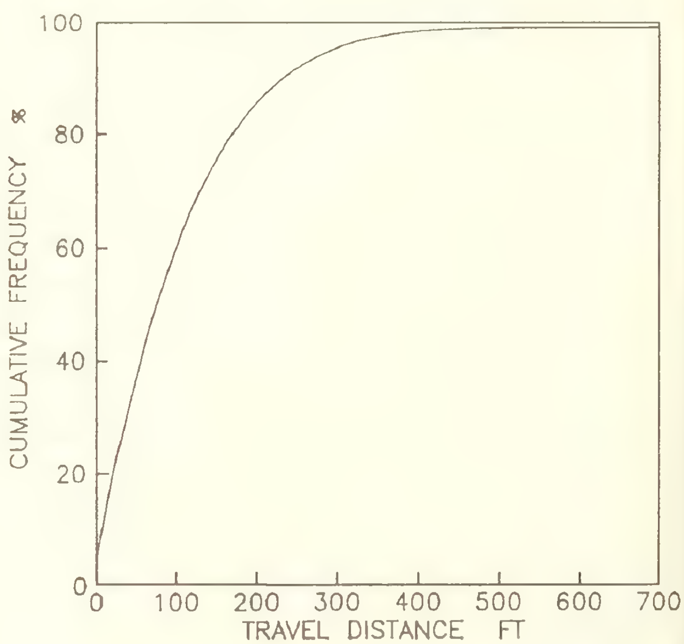

Figure 12—Cumulative frequency of sediment travel distances below fillslopes with the influence of relief culverts.

this type of data, this information could be used to estimate leave strip widths below roads on sites similar to those in Horse Creek; gneiss and schist parent material and 30 to 40 percent side slope gradients.

Cutslopes

Many of the same variables that affect fillslope surface erosion control are also applicable to the control of cutslope erosion: type of erosion control treatment, application rate for mulch treatments, the timing of treatment, slope gradient and length, and the inherent erodibility of the soil. The literature and other research results provide little information on erosion control treatments designed specifically for cutslopes. The same erosion control treatments may be used on both fillslopes and cutslopes, with the exception of wood chips and rock mulches, and hydromulch, which may not be suitable for steep cutslopes. Research on the effectiveness of these treatments often includes data from sites with slope gradients similar to cutslopes, that is, 80 to 100 percent. We will assume that estimates of erosion control effectiveness given in figures 2 through 5 will apply to both fillslopes and cutslopes. Exceptions to this general rule will be discussed where local data, experience, and observations indicate some treatments are less effective under certain conditions.

Cutslope erosion processes are often quite different from those on the fillslopes with gentler gradients. Dry raveling during the summer months is a dominant process on cutslopes, especially on noncohesive soils (Megahan 1978). In Oregon, Dyrness (1975) found that dry ravel sediment production of cutslopes in tuffs and breccias was almost as large as rain-generated sediment. Cutslope sediment production from the coarse sand Idaho Batholith soils was usually two to five times higher during the summer and early fall than during the remainder of the year (Boise State University 1984). However, the partitioning between dry ravel and rain-caused sediment was not measured. Bank sloughing when soils are saturated, especially during spring snowmelt, may produce larger soil losses than dry ravel on cohesionless soils. Of the total 2-year cutslope sediment production from border-zone gneisses and schists in the Horse Creek watersheds (Nez Perce National Forest), 80 percent was produced from November through mid-June and 20 percent during the summer and early fall. King and Gonsior (1980) observed that bank sloughing during saturated soil conditions was the dominant process.

As for fillslopes, if erosion control measures are delayed following road construction, the first-year percentage reduction in sediment for the treatment should be decreased.

Dry seeding alone provides no slope protection until germination and growth of the young plants. However, if the seed remains on the cutslope and germinates, then substantial reductions in erosion can occur. A comparison of Swift's (1984b) sediment production data for 9.5 months prior to seeding and 13.3 months following seeding, liming, and fertilization of the same cutslope, indicates an 89 percent reduction in cutslope sediment production.

Dyrness (1975) measured sediment production from 1:1 cutslope plots in western Oregon established on tuffs and breccias. Comparison of sediment production for the first year from the bare control plot and one plot that was dry seeded and fertilized indicated about a 36 percent reduction following seeding. This represents a reasonable expectation for first-year reduction in cutslope sediment provided by grass seeding.

Observations on the Nez Perce National Forest suggest that dry seeding is often not successful on 0.75:1 cutslopes unless the vertical height is less than 6 to 8 ft. However, dry seeding will produce good stands of grass if slopes can be laid back to a 1:1 or more gentle gradient (Kennedy 1986). We recommend that a 10 percent, first-year reduction in sediment be used for dry-seeding on 0.75:1 slopes with vertical height greater than 8 ft, and a 36 percent, first-year reduction on new cutslopes with a slope of 1:1 or less.

First-year sediment reductions for new 1:1 cutslopes on tuffs and breccias in Oregon treated with 2 tons per acre of straw mulch averaged about 85 percent (Dyrness 1975). Three treatments included straw mulch and different seed mixtures, and one treatment was only straw mulch. This average decreased slightly over time, and for the second through seventh year of evaluation, the reduction in sediment averaged 77 percent. The slope length for these plots was 20 to 25 ft.

Straw mulch applied with a tackifier is substantially more effective in reducing cutslope sediment production than just straw mulch. In the Horse Creek watersheds, a straw mulch (2 tons/acre) with asphalt tackifier (250 gal/acre), seed (25 lb/acre) and fertilizer application (100 lb/acre of 24-16-0) on 0.75:1 new cutslopes in border-zone gneiss and schist material reduced sediment by 32 to 47 percent over a 3-year period (King 1984). Vertical heights of these cutslopes ranged from about 3 ft to over 40 ft. On slopes laid back to 1.25:1, there was little rilling or deposition in the ditch, and the resulting stand of grass was nearly uniform. Sediment reduction on these gentler slopes probably exceeded 90 percent.

Goss and others (1970) qualitatively ranked the erosion control effectiveness of various treatments on highway fill and cutslopes and in reducing rill, sheet, and slump erosion for various slope gradients (1:1 to 3:1). For 1:1 slopes, these rankings are shown in table 3. The straw with asphalt tackifier was judged to be effective in controlling sheet and rill erosion, and straw mulch alone was slightly less effective. The ability to reduce slump erosion was rated substantially lower. For straw mulch (2 tons/acre), we recommend using sediment reduction percentages of 35 percent for 0.75:1 slopes and 40 percent for slopes at or less than a 1:1 gradient. If an asphalt tackifier is used with the straw mulch, we recommend 40 percent for 0.75:1 slopes and 75 percent for 1:1 or less steep slopes. Frost heaving or ground ice will displace portions of the mulch and reduce its effectiveness.

Table 3—Erosion control effectiveness of various treatments on 1:1 slopes (adapted from Goss and others 1970)

Erosion type	Jute net	Excelsior mat	Straw	Straw and asphalt[2]	Asphalt	Wood fiber (hydromulch)[3]	Sod
	Effectiveness rating[1]						
Sheet	9	10	8	10	6	3	10
Rill	6	10	8	10	6	3	10
Slump	10	8	6	7	3	3	8

[1]10 = most effective; 1 = not effective.
[2]Application rate for asphalt is 968 gal/acre for asphalt alone and 400 gal/acre when applied with straw.
[3]Application rate of 1,200 lb/acre.

In the summer of 1985, two types of erosion control mats were evaluated on 1:1 cutslopes with vertical heights of 8 to 12 ft. Observations of the sediment leaving the mulched cutslopes compared to sediment concentration data collected from bare slopes during simulated rainfall suggest erosion reductions of about 98 percent. These tests were conducted on border-zone gneiss and schist material on the Nez Perce National Forest. The trade names of these erosion mats are: MIRAMAT, a plastic net-type mat; and HOLD/GRO, a nylon-reinforced paper mulch. Because these were tested under simulated rainfall conditions, no evaluation was possible of their ability to control bank slough or slumping during saturated soil conditions. Swift (1987) in North Carolina observed negligible sediment from an excelsior mat reinforced with nylon netting placed over a newly seeded cutslope. One concern about the use of erosion mats on cutslopes is whether the weight of winter snowpack will drag the mat off the slope. Our observations of MIRAMAT and HOLD/GRO after two winters showed no displacement on the cutslope. The recommended sediment reduction for MIRAMAT and HOLD/GRO on 1:1 slopes is 95 percent. We assume that mass wasting processes cannot be controlled by these cutslope treatments.

In Washington, Goss and others (1970) report effective surface erosion control on 1:1 slopes using jute net mulches and excelsior matting. The performance of any mat or netting will depend on the uniformity of the slope. For example, Goss and others (1970) noticed some rill erosion under jute netting where good contact with the ground was not achieved during application. We have insufficient data to estimate the effectiveness of jute netting. For excelsior mats, we recommend a sediment reduction of 75 percent on 1:1 cutslopes and 60 percent reduction on 0.75:1 slopes.

The Missoula Equipment Development Center, USDA Forest Service, evaluated geotextile and geogrid systems that could be used for revegetating slopes (Tour 1985). They concluded that unless the vertical height of the slope is under 15 ft, slopes steeper than 1:1 should not receive mat-type erosion control applications. This conclusion was not based on erosion control effectiveness, but rather on time and labor requirements and practicality of application.

Terracing is quite effective in reducing the amount of soil leaving the cutslopes. Cutslope erosion may still be high, but eroded soil is deposited on the level terraces rather than transported off the slopes. Megahan (1984) reported that terraced and hydroseeded cutslopes constructed in Idaho Batholith granitics resulted in an 86 percent reduction in sediment production. These cutslope gradients ranged from 0.95:1 to 1.38:1. In California, Wagner and others (1979) showed that laying back a 2:1 highway cutslope to a 1.5:1 gradient and terracing the slope in decomposed granitics reduced erosion by about 94 percent. We recommend that 86 percent erosion reduction be used when new cutslopes are terraced.

Hydromulching is not very effective on steep cutslopes. Only a 10 percent reduction (not statistically significant at $\alpha = 0.1$) in sediment was realized over 3 years on 0.75:1 cutslopes on the Horse Creek watersheds. Vertical heights of these slopes were usually less than 20 ft. Bank sloughing during saturated soil conditions produced more sediment than surface erosion processes, and hydromulch is not an effective control for mass erosion. Goss and others (1970) ranked wood fiber effectiveness on 1:1 slopes low for controlling rill, sheet, or slump erosion (table 3). We recommend using a 10 percent sediment reduction for hydromulch on 0.75:1 slopes and 30 percent for 1:1 and less steep cutslopes.

Established stands of dense grass are effective in reducing erosion. An established grass stand has at least 70 percent vegetative ground cover, including plant basal area and litter.

Once grass is established on the cutslope, the recommended sediment reduction is 86 to 100 percent, depending on ground cover density. For the sixth through 14th months following seeding of sandy loam cutslopes in North Carolina, the sediment production rates were reduced 97 percent compared to the 9.5 months after construction and before cutslopes were seeded (Swift 1984b). In Oregon, an average 86 percent reduction was achieved on four newly constructed and seeded cutslope plots (three plots were also mulched) compared to a control plot, for the second through seventh year after seeding (Dyrness 1975). The same treatments on a 5-year-old eroding cutslope resulted in a net soil gain in the second through the fifth year averaging about 0.18 inch compared to a net loss of 1.55 inches from the control plot.

All of the previously discussed cutslope erosion control treatments will vary in effectiveness from site to site. Aspect, elevation, soil type, and the occurrence of frost heaving may all be important factors, but little information is available in the literature to develop any relationships with treatment effects. Additionally, ditch maintenance may

often undercut the slopes, rejuvenating the erosion process. To reiterate, local experience and observation should be used for application of the recommendations in this section.

Roadside Ditch

Reduction of sediment production from road traveledways and cutslopes, through mitigation treatments, allows water with lowered sediment concentration to flow down the ditch. This relatively clean ditch water has increased capacity to detach soil from the ditch bottom and transport it to the stream crossing.

Several methods are used to prevent erosion of the ditch bottom, ranging from paving to mats of plastic, jute, or combinations of artificial and natural materials. North American Green (1986) gives results of flume tests of several mats used as channel liners, which show 0.25 inch, or less soil loss with flow rates up to 9 ft^3/s on a 12 percent slope. These mats reduce water velocity from 56 to 78 percent and protect grass seedlings until the vegetation becomes firmly rooted in the channel section. One disadvantage to these woven mats is that routine grader maintenance on forest roads may catch the mat and rip it out.

The most common erosion control treatment for roadside ditches is a rock blanket, or riprap. The D_{50}, Dmax, and riprap thickness may be designed as a function of flow rate, channel slope, and channel shape. The design procedure outlined here was based on Highway Research Board Report 108 (Anderson and others 1970) with graphical solutions. These graphs are not convenient to use and their range does not represent forest road conditions. The basic design equations were used to develop a calculator program for a design procedure suitable for forest roads. A flow chart to illustrate the iterative procedure is shown in figure 13. Initial flow depth (d) for trapezoidal channels is estimated by a regression equation solving for d using flow rate, channel slope, channel side slopes, and a Manning's n of 0.03. The procedure may also be used for

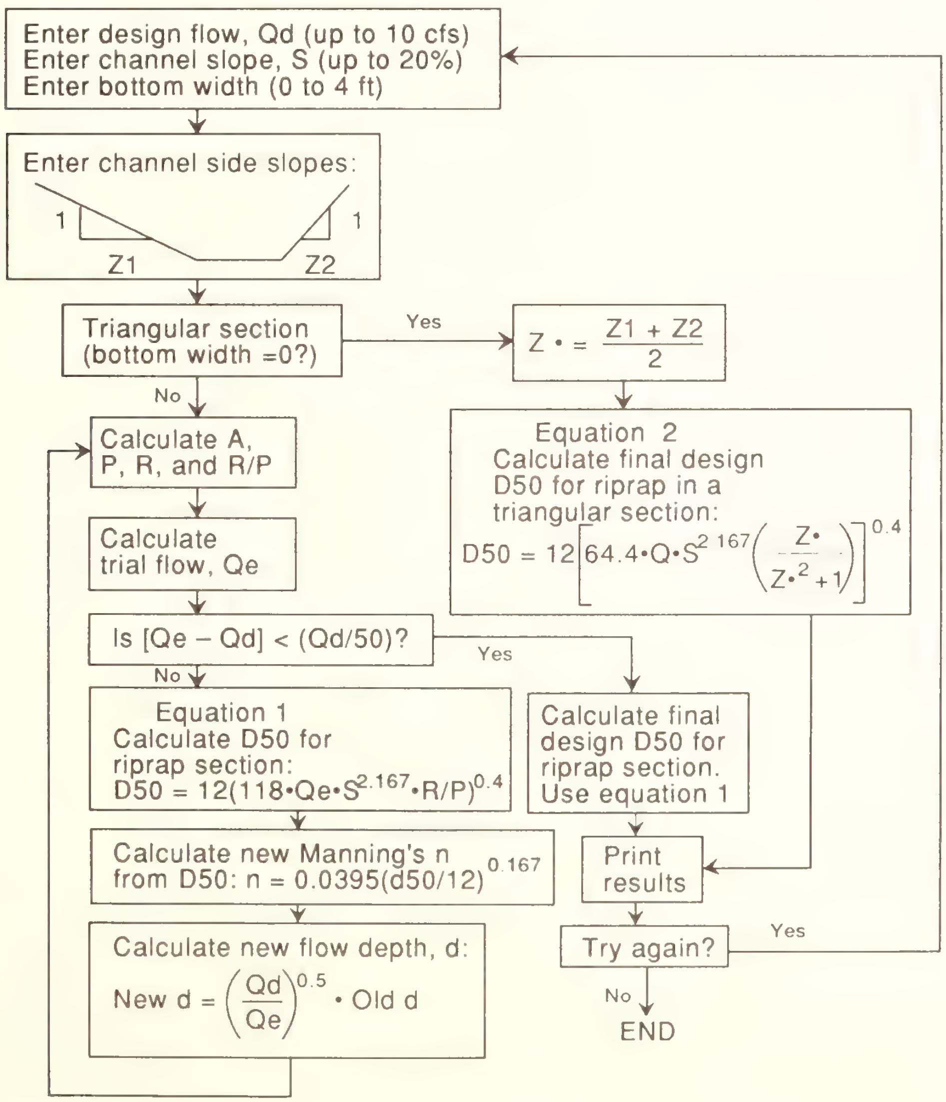

Figure 13— Flow chart for an HP-41 program to calculate riprap D_{50} for road ditches.

triangular channels. The procedure calculates the required D_{50} for riprap to maintain channel stability for the selected design factors. Copies of this program may be obtained from Burroughs, or the program may be copied from the program listing in the Appendix.

For an example, assume a 500-ft road section on an 8 percent slope draining to a road crossing. The trapezoidal ditch has a 0.5-ft bottom width, a 3:1 side slope on the road side, and a 1:1 slope on the cut side. The expected peak flow in the ditch is 0.4 ft³/s. Enter Q = 0.4, road slope = 8, bottom width = 0.5, and the two side slopes, 3 and 1. The calculated D_{50} is 2.4 inches to protect the channel bottom from this discharge on this channel slope.

An Environmental Protection Agency report (1976) recommends that the maximum size of stone in the riprap be 1.5 times D_{50}, or 3.6 inches in this example. This report also recommends that the thickness of the riprap blanket be 1.5 times the maximum rock size, but not less than 6 inches.

Another major consideration in riprap blanket design is whether a filter is required between the riprap and the underlying material (base). If the D_{50} of the base material is too fine relative to the riprap, then flowing water may pull material out of the base and allow the riprap to collapse. A criterion for determining if a filter is required is to compare the D_{50} for the two layers:

$$\frac{D_{50}\ \text{Riprap}}{D_{50}\ \text{Base}} < 40 \text{ indicates that a filter will not be needed.}$$

In the example, assume that the base material in which the road and ditch are constructed has a D_{50} of 1.1 mm. The required riprap has a D_{50} of 2.4 inches, or 61 mm. The ratio of these two is 61/1.1 or 55, which indicates that a filter is needed. One layer of plastic filter cloth is usually sufficient to separate the two materials.

In this example, the road is to be surfaced with crushed rock with an AASHO standard aggregate No. 4, with a D_{50} of about 1 inch. The peak flow rate in the ditch for the upper 150 ft of the road is estimated to be 0.07 ft³/s. The design procedure shows that the required D_{50} for riprap in the ditch is 1.0 inch. Therefore, the road surfacing material could be used in the upper 150 ft of road and the larger riprap rock used in the lower 350 ft.

Combined Erosion Control on Traveledway, Cutslope, and Ditch

Little information is available on the integrated effects of mitigation measures applied to separate components of the road prism. Tests by the Intermountain Research Station Engineering Technology project provide some insight into these questions. Simulated rainfall was applied to 100-ft-long bounded sections of forest road built in border-zone gneiss and schist in northern Idaho (Burroughs and others 1983b). One section had a gravel-surfaced traveledway, bare cutslope, and an unprotected ditch. The second section had no protection on traveledway, cutslope, or ditch. Metal barriers and gutters were used to collect traveledway runoff separately from the combined runoff from the cutslope and ditch. Several rain applications were made on the section with the graveled traveledway and unprotected ditch. Then gravel was placed in the ditch, and several more rainfall applications were made to measure the sediment reduction provided by this treatment. Next, gutters and barriers were removed so that traveledway runoff could enter the ditch, and the total sediment production from the entire section was measured over several rainfall applications. Finally, gravel was removed from the ditch so that total runoff down an unprotected ditch could be measured and the increased sediment production determined. Figure 14 provides our estimate of the combined effects of a gravel road surface with a protected ditch using the results of these barriered and unbarriered tests on both the gravel-surfaced and unprotected section.

The upper curve in figure 14 represents the sediment production to be expected from a 100-foot road section with no gravel on the traveledway or in the ditch, and an unprotected cutslope in border-zone gneiss and granite. The second curve results from a graveled traveledway and an unprotected ditch and cutslope. Reduction in sediment yield from a 100-ft road section with this treatment ranges from 27 percent for the first rainfall application to 40 percent for the last application with an average reduction of 33 percent.

The third curve represents an estimate of reduced sediment production provided by a graveled traveledway and a graveled ditch, relative to an unprotected road section. This reduction ranges from 49 percent for the first rainfall application to 67 percent for the last, with an average reduction of 57 percent. The application of gravel to the ditch in addition to the traveledway reduces sediment production by an average of 24 percent. The gravel used to protect the ditch in these tests was the same material used to surface the traveledway, 1.5-inch minus gneissic rock with a D_{50} of 0.24 inches. The riprap design program estimated a D_{50} of about 1.1 inches for a stable ditch with the flow rate, slope, and ditch shape present on this site. Degradation of the ditch bottom at the lower end of the plot was measured during these tests, which indicates that coarser gravel should have been used to stabilize the ditch bottom. If so, then the reduction in sediment yield provided by graveling the ditch would have been greater than shown by these tests. This also suggests that the unprotected ditch may be a greater source of sediment than the unprotected traveledway, at least for roads with a low traffic volume.

The bottom curve is an estimate of the additional sediment reduction provided by protecting the cutslope. For this estimate, we assumed that the cutslope protection was 80 percent effective and that the graveled ditch did not itself provide any significant sediment. This hypothetical curve was derived by subtracting an additional 80 percent of the sediment production from the graveled road/graveled ditch curve. The estimated sediment reduction provided by graveling the traveledway and ditch and protecting the cutslope averages 91 percent.

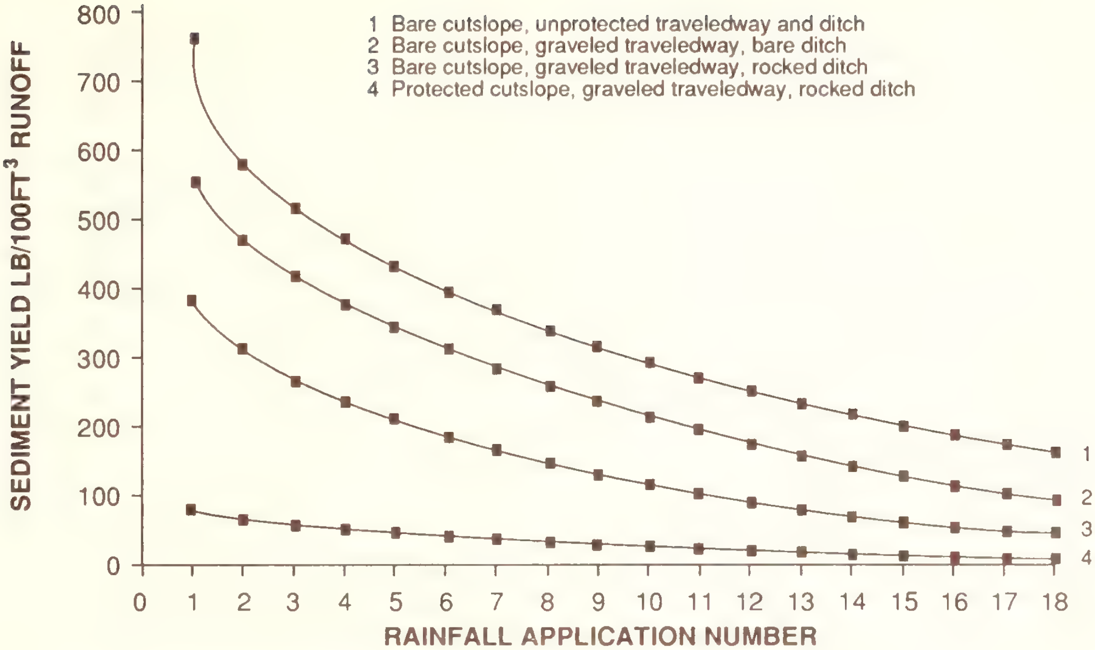

Figure 14—Partitioning of sediment yield between components of the road prism.

Other items should be noted. The effect of surface armoring is quite pronounced as rainfall and runoff detach and remove fine soil particles and cause a progressively coarser surface texture. Keep in mind that these curves result from simulated rainfall on two 100-ft sections of road. Therefore, these results are accurate only for the relative differences in sediment production provided by various mitigation treatments. The values of sediment production in pounds per 100 ft^3 of runoff should not be used to represent results of natural rainfall or snowmelt.

The results of the simulated rainfall study for partitioning road sediment did not include a bounded section of the fillslope that would have allowed comparison of relative sediment yields between all road features. However, information is available from one instrumented road section at a stream crossing on a similar geology and soils. The road, one of the Horse Creek roads on the Nez Perce National Forest, did not have any erosion control treatments on the cuts or fills, and the road traveledway was unsurfaced. Instruments to measure stream discharge and sediment concentration were installed at three sampling sites along the stream channel (fig. 15): upstream from the road (station A), at the outfall of the culvert passing the stream (station B), and about 150 ft downstream from the road (station C). The road was built in the summer of 1979, and the stations were placed in operation at the end of the summer and continued to operate for 4 years.

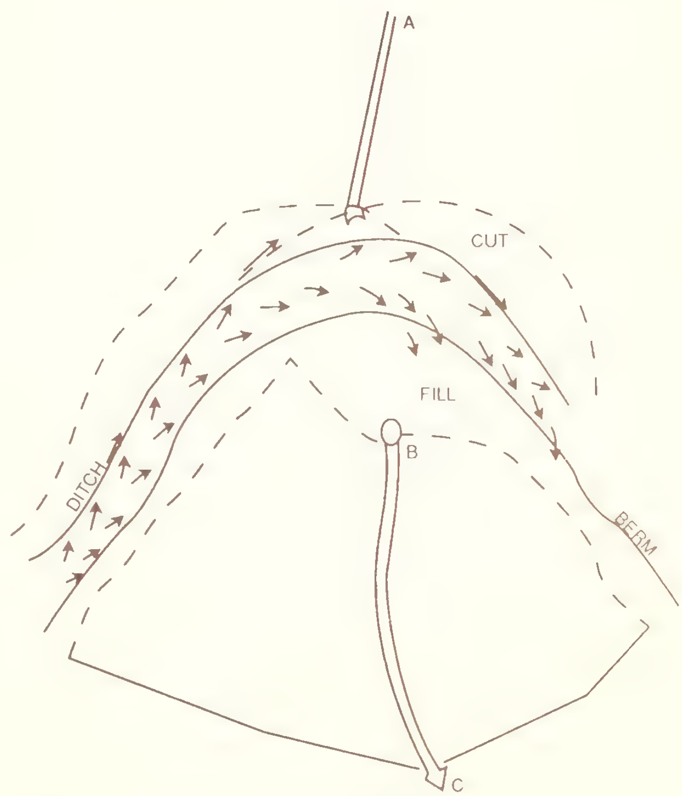

Figure 15—Road features and flow paths for the Horse Creek stream crossing with no erosion control measures.

These stations allow for partitioning the sediment by that amount contributed via the ditch system and that amount reaching the stream from the fill slope side of the road. The increase in sediment yield between stations A and B is the sediment delivered to the stream via the ditches, which would include eroded material from the cutslopes, ditches, and a portion of the traveledway. The increase in sediment yield between stations B and C is the sediment reaching the channel from the fillslope side of the road, which includes eroded material from the fillslopes and a portion of the traveledway, plus or minus channel storage. Figure 15 shows the road features, drainage flow paths, and contributing areas to the stations.

This road section is unusual in that the traveledway is crowned and drains to both the ditches and the fills. Another unusual feature is a berm along much of the outside edge of the traveledway that carries water along it for some length. This water is then diverted onto the unprotected fills in two locations, one of which is directly above the channel. This berm was not a designed feature in the road but was created during construction and maintenance grading. Table 4 gives the areas of each road feature contributing to the A and B stations. Note that the majority (72 percent) of the traveledway that influences this stream drains onto the fillslopes.

The percentage of the total annual stream sediment that is contributed via the ditch or fillslope side of the road varies over time (table 5). During the first year after construction, 80 percent of the sediment reached the stream via the fillslope side of the road. After 4 years the situation is reversed, and 83 percent of the sediment is contributed via the ditch system. Over the entire 4 years, 47 percent of the sediment reached the stream from the fillslope side of the road. These results and supporting measurements of fillslope erosion and observation of sediment and water-flow paths indicate that during the first year following road construction at this stream crossing, the unconsolidated fillslopes near the stream generated the majority of the stream sediment. Fillslope erosion was increased by drainage from the traveledway immediately above the channel.

This case study of a bermed road suggests that during the first year following construction, erosion control measures on the fillslopes or immediately below the fillslopes would be more effective in reducing stream sediment than measures to control cutslope and ditch erosion. However, as the less steep fillslopes become armored and revegetated, then the primary source of sediment is ditch and cutslope erosion. The results also suggest the need to avoid undesigned berms that concentrate traveledway drainage and then divert it onto the fillslopes. Insloping the road to the ditch or a more uniform spacial distribution of traveledway drainage onto the fills would considerably reduce fillslope contributions of stream sediment. This would require care during routine blading to avoid altering the designed traveledway drainage such as creating an undesigned berm along the outside edge of the traveledway.

Table 4—Plan view areas of the road features contributing to B and C sampling stations

Road feature	B station	C station	Total
	- - - - - - - - - - - -	*Ft*^{2} - - - - - - - - - - - -	
Cutslope	3,478		3,478
Ditch	1,104		1,104
Traveledway	1,875	4,847	6,722
Fillslope		7,503	7,503

Table 5—The partitioning of total road sediment entering the stream via the ditch system and the fillslope side of the road for the 4 years following construction

Sediment source	Years 1980	1981	1982	1983	Average
	- - - - - - - - -	*Percent of total*	- - - - -	- - - - -	
Via the ditch	20	48	60	83	53
Via the fillslope side of the road	80	52	40	17	47
Total road sediment at C station, lb	2,492	2,132	6,997	1,317	

CONCLUSIONS

This paper provides land managers with a summary of the effectiveness of various road treatments and practices in reducing erosion and sediment transport. We have not included an exhaustive summary of all related research, but we have provided information to improve estimation of sediment yield from roads and to improve the decision-making process. Again, experience and professional judgment are required in relating many of these results to local situations.

Development continues on methods to reduce onsite erosion from forest roads. This research is now part of a Forest Service study of onsite erosion from roads and disturbed forest sites nationwide. The goal of this long-term study is to develop a physical process model of onsite erosion using easily measured site characteristics with user-selected hydrologic events to evaluate alternative land management treatments. This effort to develop a forest onsite sediment model is part of a larger cooperative effort with the U.S. Department of Agriculture, and Agricultural Research Service, Soil Conservation Service, and U.S. Department of the Interior, Bureau of Land Management, to predict soil erosion from croplands, rangelands, and forests.

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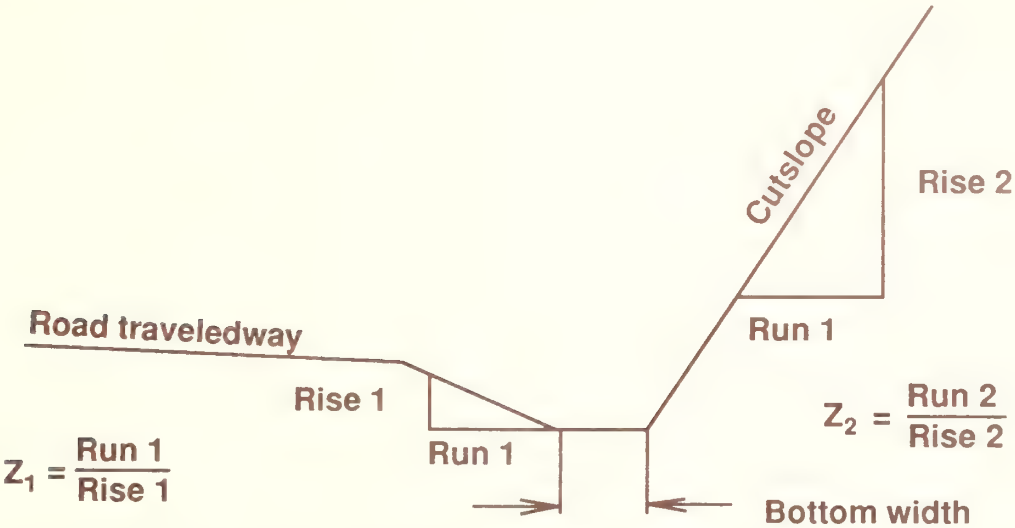
APPENDIX: HP-41 PROGRAM TO DESIGN RIPRAP FOR CHANNEL PROTECTION

Road Ditch Cross Section



(Use a bottom width = 0 for triangular ditch cross sections.)

Example Calculations

Example 1

```
   RIPRAP
   DESIGN
    MARCH 1989

Q, CFS = 0.100
DITCH SLOPE, % = 21.00
SLOPE > 20, TRY AGAIN
DITCH SLOPE, % = 6.00
BOTTOM WIDTH, FT = 0.50
Z1 =RUN1/RISE1= 3.00
Z2 =RUN2/RISE2= 1.00
D50=  1.23 IN.
```

Example 2

```
   RIPRAP
   DESIGN
    MARCH 1989

Q, CFS = 0.200
DITCH SLOPE, % = 8.00
BOTTOM WIDTH, FT = 0.00
Z1 =RUN1/RISE1= 3.00
Z2 =RUN2/RISE2= 1.00
D50=  2.59 IN.
END
```

Program Printout

```
01♦LBL "RIPRAP"
02 SF 12
03 "   RIPRAP"
04 XEQ "PRA"
05 "   DESIGN"
06 XEQ "PRA"
07 CF 12
08 "        MARCH 19"
09 "⊢89"
10 XEQ "PRA"
11♦LBL "D3"
12 ADV
13 CF 01
14 CF 02
15 CF 03
16 .03
17 STO 08
18 FIX 3
19 "Q, CFS ="
20 PROMPT
21 XEQ "ACA"
22 XEQ "ACX"
23 XEQ "PRBUF"
24 STO 01
```

```
25♦LBL "C2"
26 20
27 FIX 2
28 "DITCH SLOPE, % "
29 "⊢="
30 PROMPT
31 XEQ "ACA"
32 XEQ "ACX"
33 XEQ "PRBUF"
34 STO 02
35 X<=Y?
36 GTO B

37♦LBL "C1"
38 "SLOPE > 20, TRY"
39 "⊢ AGAIN"
40 AVIEW
41 GTO "C2"

42♦LBL B
43 SF 03
44 "BOTTOM WIDTH, F"
45 "⊢T ="
46 PROMPT
47 XEQ "ACA"
48 XEQ "ACX"
49 XEQ "PRBUF"
50 STO 03
51 0
52 X=Y?
53 GTO "TRI"
54 X>Y?
55 GTO B
56 X<>Y

57♦LBL "TRAP"
58 .0733
59 Y↑X
60 RCL 01
61 -.0279
62 Y↑X
63 *
64 .2723
65 *
66 CHS
67 RCL 02
68 X<>Y
69 Y↑X
70 RCL 03
71 -.4349
72 Y↑X
73 RCL 01
74 .5363
75 Y↑X
76 *
77 .3245
78 *
79 *
80 STO 04
81 GTO "S"
82♦LBL "TRI"
83 SF 01

84♦LBL "S"
85 "Z1 =RUN1/RISE1="
86 PROMPT
87 XEQ "ACA"
88 XEQ "ACX"
89 XEQ "PRBUF"
90 "Z2 =RUN2/RISE2="
91 PROMPT
92 XEQ "ACA"
93 XEQ "ACX"
94 XEQ "PRBUF"
95 +
96 2
97 /
98 STO 00
99 FS? 01
100 GTO "D2

101♦LBL A
102 RCL 04
103 RCL 00
104 *
105 RCL 03
106 +
107 RCL 04
108 *
109 STO 05

110♦LBL "P"
111 RCL 04
112 2
113 *
114 RCL 00
115 X↑2
116 1
117 +
118 SQRT
119 *
120 RCL 03
121 +
122 STO 07

123♦LBL "R"
124 /
125 STO 06

126♦LBL "R/P
127 RCL 07
128 /
129 STO 07

130♦LBL "QE"
131 1.486
132 RCL 08
```

```
133 /
134 RCL 06
135 .667
136 Y↑X
137 *
138 RCL 02
139 100
140 /
141 SQRT
142 *
143 RCL 05
144 *
145 STO 09
146 FS?C 03
147 GTO "D1"
148 RCL 01
149 50
150 /
151 RCL 09
152 RCL 01
153 -
154 ABS
155 X<=Y?
156 SF 02

157♦LBL "D1"
158 RCL 01
159 118
160 *
161 RCL 02
162 100
163 /
164 2.1667
165 Y↑X
166 *
167 RCL 07
168 *
169 .4
170 Y↑X
171 GTO "H"

172♦LBL "D2"
173 RCL 01
174 64.4
175 *
176 RCL 02
177 100
178 /
179 2.1667
180 Y↑X
181 *
182 RCL 00
183 RCL 00
184 X↑2
185 1
186 +
187 /
188 *
189 .4
190 Y↑X
191 STO 10
192 CF 01
193 GTO D

194♦LBL "H"
195 STO 10
196 FS?C 02
197 GTO D
198 .1667
199 Y↑X
200 .0395
201 *
202 STO 08

203♦LBL "ADJ"
204 RCL 01
205 RCL 09
206 /
207 SQRT
208 ST* 04
209 GTO A

210♦LBL D
211 RCL 10
212 12
213 *
214 "D50= "
215 XEQ "ACA"
216 ARCL X
217 XEQ "ACX"
218 " IN."
219 XEQ "ACA"
220 XEQ "PRBUF"

221♦LBL "Q"
222 "TRY AGAIN? Y OR"
223 "⊢ N"
224 AON
225 PROMPT
226 AOFF
227 ATOX
228 78
229 X=Y?
230 GTO 99
231 X<>Y
232 89
233 X=Y?
234 GTO "D3"
235 GTO "Q"

236♦LBL 99
237 "END"
238 AVIEW
239 STOP
240 .END.
```

Burroughs, Edward R., Jr.; King, John G. 1989. Reduction of soil erosion on forest roads. Gen. Tech. Rep. INT-264. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 21 p.

Presents the expected reduction in surface erosion from selected treatments applied to forest road traveledways, cutslopes, fillslopes, and ditches. Estimated erosion reduction is expressed as functions of ground cover, slope gradient, and soil properties whenever possible. A procedure is provided to select rock riprap size for protection of the road ditch.

KEYWORDS: surface erosion, erosion reduction, forest roads

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Low-Impact Recreational Practices for Wilderness and Backcountry

David N. Cole

THE AUTHOR

DAVID N. COLE is research biologist and Project Leader for the Intermountain Station's Wilderness Management Research Work Unit at the Forestry Sciences Laboratory, Missoula. Dr. Cole received his B.A. degree in geography from the University of California, Berkeley, in 1972. He received his Ph.D., also in geography, from the University of Oregon in 1977. He has written many papers on wilderness management, particularly the ecological effects of recreational use.

PREFACE

This report summarizes information on low-impact recreational practices in backcountry and wilderness areas. The first section describes common problems caused by recreational use of backcountry and factors that influence the magnitude of these problems. Low-impact practices capable of substantially attenuating these problems are listed.

The second section—the bulk of the report—describes each low-impact practice, using a standard format. First, the practice is described along with sample messages for recreationists. Then the rationale for each practice is discussed, as is the importance and likely effectiveness of the practice. Controversial aspects of recommended practices and knowledge needed to increase specificity or reduce controversy are discussed. The frequency with which each practice is recommended is noted, and costs to visitors are described.

A third section discusses practices that have been recommended but that might result in problems. This section is followed by a discussion and examples of messages that emphasize visitors' understanding the rationale behind recommended low-impact practices and messages tailored to different environments and user groups. A final section discusses major research gaps in knowledge about behaviors capable of minimizing problems.

This report is intended to serve as a source book of information on low-impact practices. Managers can use the discussion of problems to identify practices they might want to recommend to visitors. The descriptions of individual practices can be used to decide more specifically what practices to recommend. The sections on developing effective messages can provide ideas and examples on how to put together a coherent set of recommended practices. The section on research gaps might prove useful to researchers seeking important topics for study.

There are three primary ways of accessing information on specific practices. Someone interested in all of the practices useful in avoiding specific problems can use the lists following the discussions of each management problem. Major categories of practices, such as all those that pertain to the use of campfires, can be located in the table of contents. Specific practices are listed in appendix A.

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Intermountain Research Station
324 25th Street
Ogden, UT 84401

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INTRODUCTION

Wilderness and backcountry areas have been designated for a variety of purposes and permit a variety of uses. These various purposes and uses often conflict with each other, causing management problems. Recreational use is a good example. Recreational use can alter vegetation, animal behavior, soil, and water, compromising the integrity of ecological, geological, scientific, scenic, and historical values. By diminishing opportunities for solitude, recreational values can also be compromised. Management problems resulting from recreational use of wilderness and backcountry (terms that will be used interchangeably hereafter) can and have been dealt with in many ways. Cole and others (1987) discuss the pros and cons of alternative strategies for dealing with these common problems.

As wilderness use and its impacts have grown in magnitude, so have restrictions on that use. Regulations have proliferated, resulting in a new problem—restriction of the free and spontaneous nature of wilderness recreation. Ever-increasing regulation has precipitated concern that management has become unnecessarily authoritarian (Lucas 1982). An alternative approach has been advanced, stressing information and education. If informed users will voluntarily behave in ways that minimize problems, then regulation can be less pervasive.

The notion that management through voluntary compliance is preferable to authoritarian control has considerable appeal to managers and visitors alike. Most managers are uncomfortable with the "police" role that regulation requires of them, and visitors usually prefer to retain freedom of choice. Consequently, both managing agencies and advocates of recreational use have been quick to express their support for information and education programs (Frome 1985). Considerable progress in the development of written materials about low-impact practices has been made. Techniques are taught in "how-to" books (for example, Hart 1977; Petzoldt 1974; Simer and Sullivan 1983), books specifically on low-impact techniques (Hampton and Cole 1988; Waterman and Waterman 1979), popular articles (for example, Curtis 1982; Hart 1980; Manning 1980; Wallace and DeBell 1982), and in brochures and pamphlets developed by land-managing agencies and user groups. Low-impact practices are also presented through such media as video, slide tapes, and face-to-face contact between rangers and visitors (Martin and Taylor 1981).

Although much thought has gone into development of these materials, there has been virtually no formal evaluation of the accuracy or effectiveness of the practices that have been recommended. Most recommendations are commonsense judgments derived from personal experience and are generally accepted. Some of these recommendations are contradictory and controversial, however. Moreover, research results relevant to predicting likely consequences of recommended actions have often been overlooked, and rationales for recommended actions have seldom been developed.

Considering the time and effort being expended on developing low-impact educational programs, it seemed worthwhile to systematically review current knowledge and experience. The development of effective wilderness education will require understanding of both *what* information to provide and *how* to convey this information to visitors. This report addresses the "what" aspect, the content of educational messages. What should we be telling wilderness visitors?

This report does *not* address the question of how to effectively deliver these messages. This subject will require innovative thinking, experimentation, and analysis. To date, Martin and Taylor (1981) have compiled the most comprehensive report on this subject.

Most of this report consists of two sections. The first section describes major management problems, and the characteristics of visitor use and behavior that aggravate each problem. Practices are identified that will minimize each problem. By linking recommended practices to specific problems, it is easier to provide a rationale for practices and to evaluate the likely

effectiveness of each recommendation. Providing good reasons for recommendations is generally considered important to getting visitor compliance. Clear definition of linkages between problems and practices is also critical when evaluating the appropriateness of recommendations that have both positive benefits and negative consequences.

The second major section describes both generally recommended low-impact practices and frequently recommended practices that may be counterproductive. To prepare this section, 90 examples of low-impact materials were collected from a variety of sources and regions of the Nation. The recommendations provided were evaluated for consistency among sources and with the results of research. Most practices can be generally recommended. A number of recommended practices are controversial, however. Some have potentially negative consequences. For some of these, the negative consequences can be predicted given current knowledge; for others, tests of effectiveness are needed. Controversy also results from making recommendations that are arbitrary, overly specific, or that apply in some situations but not in others. Finally, a number of recommendations would be more useful if they were more specific, but further research is needed to provide this specificity.

In this report, "controversy" refers to differences of opinion about appropriate low-impact recommendations or situations where research results conflict with recommendations. A major objective of this report is to highlight and, where possible, resolve these controversies. The term is not used to refer to recommendations that are controversial to users who object to a generally recommended practice. For example, there is little controversy about the validity of recommending that stoves be used instead of fires in popular timberline destination areas. Nevertheless, many visitors may find this recommendation controversial because they are accustomed to and enjoy campfires.

In addition to the two major sections, this report discusses the importance of, and how to tailor, low-impact messages to specific user groups and environments. Although some practices are universal, the applicability of others varies, depending on whether the user travels on horseback or carries a backpack; and whether the visit is to desert or to alpine tundra. Comprehension and retention are likely to be greater when information is targeted more specifically and the information provided can also be more specific, making it more useful. Other sections of this report describe gaps in knowledge, provide examples of educational materials, and describe some desirable characteristics of such materials.

EDUCATION—A PERSONAL VIEW

Many of the low-impact educational materials I reviewed were simply lists of "do's and don'ts"—things to do and things not to do. Such lists are strikingly similar to lists of rules and regulations. The primary difference is that the lists of do's and don'ts used words such as "discouraged" instead of "prohibited", or "encouraged" rather than "required." Often the only difference in phraseology is whether or not the statement is backed up by Federal regulations. It has been argued that this difference is important because visitors retain freedom of choice (Lucas 1982). I do not disagree, and I believe that lists of do's and don'ts can be useful. But I also believe that the type of education that is needed to reduce impacts substantially is something very different.

Educational programs need to do more than teach visitors what to do. Such programs must change the way people think about their behavior. Simply changing what visitors do would be effective if it were possible to list a set of practices that were appropriate in all circumstances. Unfortunately, this is not possible. The right practice in one situation can be the worst thing to do in another situation. For example, when following a trail, parties should walk single file down the middle of the trail. When walking off-trail, however, people should spread out to avoid creating a trail.

Visitors need to be taught how to evaluate and weigh a variety of factors, and how to select the course of action most likely to minimize problems. They need to use judgment, as well as follow specific techniques for minimizing impact.

Teaching visitors how to evaluate different situations would produce additional benefits. It would provide a framework for incorporating new information and experience. As will become obvious in the entries for "knowledge needs" in the descriptions of practices, there is a lot that we do not know about low-impact practices. A framework for organizing new knowledge would help each person to continually improve low-impact skills. Commitment to low-impact techniques is also likely to be greater if visitors possess a framework for evaluating appropriate behavior. Satisfaction should be greater after having figured out the right thing to do, instead of simply complying with a recommended practice. The reasons for and importance of behaving in certain ways should also be more apparent.

Educational programs tend to provide little rationale for recommendations. For example, visitors are commonly asked not to camp close to lakes; however, defensible reasons for this request are seldom offered. Without a rationale, visitors may not understand why the action is important and may decide that it is *not* important. They are more likely to interpret recommendations incorrectly, and they are less likely to think of additional means of mitigating the problem. The need to pay more attention to rationale is the primary motivation for the discussion of problems in the subsequent section.

Programs also suffer from a common belief that it is necessary to state practices as universal rules. This tendency reflects a common opinion that most visitors are incapable of making complex judgments—a debatable point. Unfortunately, it is not possible for all recommendations to be simple rules that apply everywhere. Walking silently to maintain solitude seems to be a universally good idea, but in grizzly bear country one wants to make lots of noise to avoid surprising bears. Advice about where to camp is much more complicated, with many more variations and tradeoffs. It simply cannot be reduced to a set of universal do's and don'ts. Clearly the best choice is to train visitors in the art and science of making judgments based on a variety of factors.

In sum, low-impact wilderness education must be an ethic and a way of thinking if it is to realize its full potential. It is more a matter of attitude and awareness than of rules and regulations. Otherwise, educational programs will differ little from a system of officially sanctioned rules and regulations. Visitors need to be aware of the most critical management problems and the actions they can take to minimize those problems. They must learn how to evaluate a variety of factors—such as soil, vegetation, wildlife, weather, the amount and type of use a place receives—and then use this analysis and past experience to select appropriate practices. This requires both respect for and trust of visitors. A large proportion of wilderness visitors are well educated (Roggenbuck and Lucas 1987). Where visitors will not cooperate voluntarily, there is little choice other than management through regulation and law enforcement.

Implementing low-impact education is a difficult task that will take considerable time and effort. It represents a long-term goal. Similarly, certain recommendations in this report may appear overly "pure." They clearly would require dramatic changes on many users' part; however, they are not as "pure" as some reviewers wanted. Again, I advance these practices as reasonable long-term goals.

In the short term, practical considerations will preclude highly ambitious educational programs and expectations of immediate changes in behavior. It will be necessary to begin by teaching relatively simple practices and concepts and to nudge users away from traditional high-impact practices. Nevertheless, it is important to keep long-term goals in mind.

MANAGEMENT PROBLEMS

Management problems could be discussed at various levels of generalization. All problems resulting from recreational use of wilderness could be sorted into two categories—adverse ecological impacts and adverse impacts on visitor experiences. At the other extreme, it would be possible to list scores of different types of ecological impacts at campsites (tree damage, vegetation loss, campfire damage, and so on). A useful intermediate level of analysis used elsewhere (Cole and others 1987) identifies eight major types of problems, several of which have been divided into subproblems. These will be discussed in order of their perceived prevalence in wilderness (Washburne and Cole 1983). After each subproblem, the low-impact practices judged to be most important to minimizing problems are listed.

Trail Problems

Most problems associated with constructed trails result from poor trail construction and maintenance rather than either too much use or improper use of the trail (Cole 1983a; Helgath 1975). Two useful guides to trail construction and maintenance are Birchard and Proudman (1981) and Proudman and Rajala (1981). Although most deterioration problems would not occur if trails were properly located and/or engineered (management actions outside the realm of visitor education), certain types of visitor behavior aggravate trail deterioration. A second subset of trail problems results from the development of user-created trails in places where trails are unwanted. These two subproblems will be treated separately.

Deterioration of Constructed Trails—The most common types of deterioration on constructed trails are erosion, muddiness, trail widening (often the result of a muddy trail), and the creation of multiple trails and switchback shortcuts (Cole 1987b). As just mentioned, proper location, engineering, and maintenance of constructed trails are the most effective

means of avoiding these problems. In certain locations, without necessary engineering, any use will result in erosion and muddiness. The tendency, however, for visitors to leave the constructed trail, where these conditions exist, exacerbates these problems. Where trails are narrow and deep, or wet and muddy, the natural tendency is to walk along the edge of the trail rather than in the trail tread. This causes widening of muddy quagmires and/or the development of multiple parallel trails. Similar problems result from leaving the trail to shortcut a switchback. The shortcut becomes a trail (usually steep), is used more frequently, and deteriorates rapidly.

Two other factors influence the severity of deterioration problems. Trails are more prone to muddiness, widening, and the development of multiple trails when the ground is wet and water-saturated. While these conditions may occur sporadically and unpredictably (such as after summer thunderstorms), they may be particularly prevalent at certain seasons, such as during and shortly after snowmelt. Avoiding use at this time can effectively reduce the potential for trail deterioration.

Finally, compared to hiking parties, parties with packstock have more potential to cause trail deterioration (Weaver and Dale 1978). Where parties with packstock leave the constructed trail, deterioration occurs rapidly. Similarly, the potential for damage during seasons when soils are water saturated is particularly high when parties travel with stock. Therefore, all of the low-impact practices intended to minimize deterioration of constructed trails are considerably more important for parties with packstock.

For hiking parties the most important low-impact practices are:

Avoid trips where and when soils are wet and muddy (page 20).
Walk single file and keep to the main tread (page 31).
Do not shortcut switchbacks (page 34).

All of these practices are particularly important for parties that travel with stock. In addition, the following important practices are unique to parties with stock:

Use properly trained stock (page 78).
Minimize the number of stock (page 80).
Stock should stay on established trails as much as possible (page 81).
Remove trail obstacles instead of skirting them (page 82).
Lead stock on the trail, rather than loose-herd them (page 83).

Development of Undesired User-Created Trails—Undesired user-created trails develop along popular cross-country routes and in popular destination areas. They result from too many feet trampling the same strip of vegetation and ground. Many of these trails were previously animal trails, altered by the trampling of animal hooves. The problem is that obvious paths tend to attract more use, which results in further development of a trail system. Unplanned trail systems are often poorly located, so erosion can be particularly severe even with low use. They also tend to braid and proliferate widely, eventually resulting in more alteration than would have been the case with construction of a planned trail. More areas are developing specific objectives to keep areas trailless; such trail systems clearly defeat these objectives.

User-created trails result from too many people following in precisely the same path. The major way to avoid this is to have people spread out. This reduces the frequency any single place gets stepped on. The number of times any place can be stepped on before a trail develops depends on the fragility of the ground surface and the destructive force of the trampler. Therefore, trails are more likely to develop on fragile vegetation and ground surfaces or during seasons when the ground is water-saturated. They are also more likely to develop when trampled by stock, rather than by hikers (Weaver and Dale 1978). Similarly, where it is difficult to spread out, trail development is more likely following the passage of a large party because more feet are likely to fall on the same path.

In some places, use levels are so high that spreading out would simply create many trails all over the place. Ideally, management should establish an "official" trail system in such places (or reduce use levels dramatically). Where managers have taken neither of these actions, users can help the situation by treating the most obvious of the user-created trails as a constructed trail and staying on it. While this will not avoid the creation of user-created trails, it will limit their proliferation.

For hiking parties, the most important low-impact practices are:

Keep party size small (page 18).
Avoid trips where and when soils are wet and muddy (page 20).
Avoid off-trail travel unless prepared to use extra care (page 22).
Avoid walking on closed trails and/or developing user-created trails (page 30).
Spread out when walking off trail (page 37).
Do not mark cross-country routes (page 38).
Choose a cross-country route that crosses durable surfaces (page 39).
When traveling cross country, use extra care when ascending or descending steep slopes (page 40).

All of these practices are particularly important for parties that travel with stock. Except in resistant environments, it is difficult for a party of stock to not create a new trail. Therefore, use of existing trails is always preferable to cross-country travel; parties that do choose to travel cross country must use extra care. In addition to the preceding practices, the following are unique to parties with stock:

Use properly trained stock (page 78).
Minimize the number of stock (page 80).
Stock should stay on established trails as much as possible (page 81).

Campsite Problems

The nature and magnitude of campsite problems are influenced by a variety of factors. The most important factors are how frequently the site is camped on, the type of party that uses the site (particularly size of party and whether or not they have stock), the behavior of campers (including, particularly, whether or not they have a campfire), and the fragility of the site (Cole 1987b). Season of use can also affect fragility and, therefore, is sometimes a significant factor. Low-impact practices are available that can take advantage of the influence of each of these factors.

Extensive research has shown that the relationship between frequency of use and amount of impact is complex; it varies with the use levels being compared (Cole 1987b). When comparing two infrequently used campsites, the more frequently used site is likely to have experienced considerably more impact. This is not the case when comparing more frequently used sites, however. Levels of impact may be comparable on sites receiving quite different levels of use. The major implications of this finding are: (1) keeping use of infrequently used sites to very low levels is an effective means of minimizing impact on these sites; (2) on the other hand, lightly used and lightly impacted sites, if used more frequently, are likely to deteriorate dramatically; and (3) on frequently used sites, neither increasing nor decreasing use is likely to have a substantial effect on amount of impact (Cole and Benedict 1983). But whenever use levels are reduced on certain sites, other sites will be used more frequently and the potential for the creation and deterioration of new sites increases. As long as use frequencies remain extremely low on all sites, deterioration may not occur and use dispersal may not lead to site proliferation. Where it is not possible to maintain very low frequencies on sites, use dispersal will merely increase the number of impacted sites (Cole 1982a).

These findings and implications suggest two positive ways to limit campsite problems and one situation that should be avoided. Because increased use of frequently used sites is not likely to cause much further damage, camping on sites that are already well impacted will confine deterioration to a small number of sites. Alternatively, where it is possible to use sites so infrequently that they never deteriorate, camping on apparently undisturbed sites will avoid the creation of campsites entirely. The situation to avoid is use of a large number of sites at low-to-moderate frequencies sufficient to cause site deterioration. This situation can occur either in popular places or in remote, little-used places. In popular places, it results from camping on less-disturbed sites rather than on sites that are already heavily impacted. In remote places, the problem results from camping on sites that have already been disturbed. This is likely to cause further disturbance, which is likely to attract further use, which is likely to cause further disturbance, and so on. *The key—in both popular and remote places—is to never camp on sites that are obviously but lightly disturbed* (Cole and Benedict 1983).

Type of use and visitor behavior can have a substantial influence on the severity of campsite problems. Large parties and parties with packstock will disturb a larger area than will a small hiking party (all other factors being equal) because they must occupy a larger area (Cole 1983b). Campsites used by outfitted parties tend to be particularly large because these parties usually consist of a number of unaffiliated groups, each seeking some privacy (Cole and Marion 1988). Unless such parties can find an existing site that is already large enough to accommodate their group, they are likely to enlarge the area of disturbance. Enlargement is the most common detrimental ongoing change on well-established campsites (Cole 1986a). Large parties and parties with stock will also tend to disturb a pristine site more rapidly than will a small hiking party. This follows from the facts that stock hooves cause more disturbance than human feet (Weaver and Dale 1978) and that the frequency any place is trampled will increase as party size increases. Therefore, large parties and parties with stock must use extra care when camping in little-used places.

Regardless of type of use, certain behaviors cause unnecessary impact while other behaviors minimize impact. Campfires, particularly if not used with restraint and caution, cause some of the most obtrusive impacts on campsites. Parties that carry and use stoves and do not build fires avoid these impacts. Damage can also be reduced by building fires carefully, only in appropriate places, and by cleaning up after fires. Avoiding any intentional site alteration and camouflaging any inadvertent disturbance that does occur are also important, as is traffic flow on the site. Again, the appropriate principle is that it is best to spread use and impact on undisturbed sites and to concentrate use and impact on areas that are already highly impacted. Thus, on already impacted sites, tents and activities should be confined to the most disturbed parts of the site. Conversely, tents and activities should be spread out on undisturbed sites. Large groups can minimize their disturbance of pristine places by breaking up into small groups that camp some distance from each other.

Finally, it is possible to take advantage of the fact that sites vary in their ability to tolerate use. Differences in the durability of vegetation are greater where use levels are low rather than high (Cole 1987a). This follows from the fact that, given sufficiently frequent use, even resistant vegetation (such as the turf of a football field) will be removed. This means that seeking out resistant sites is most important when using an apparently undisturbed site. Sites that are entirely devoid of vegetation are always preferred. Sites on rock, unconsolidated mineral soil (for example, beaches or dry washes), snow, or ice are best for minimizing impact; however, they may not be attractive to many campers. Where vegetation is present, sites with resistant vegetation are preferred. Vegetation resistance is highly variable, making it difficult to provide generalizations that apply in different regions or even within local areas. Vegetation types dominated by grasses and grasslike plants, particularly if growth is dense and short, are usually relatively resistant, as are vegetation types with large, tough shrubs with bare soil between (Cole 1986b). On frequently used sites, no vegetation type is tough enough to survive; however, some sites have a greater ability to avoid mineral soil exposure than others. This is significant because soil compaction and erosion tend to be more severe where soil exposure is pronounced. Potential for soil exposure is least on flat sites with thick organic horizons (Cole 1985).

As with trail problems, it is useful to divide campsite problems into two subproblems. The first is excessive deterioration of established campsites, whether officially designated or spontaneously created by users. This is the type of problem most readily envisioned—large areas of barren, compacted, and eroded soil; hacked-up and sawed-down trees with exposed roots; numerous firerings with charcoal spread over the site; plank seats; tables; ditched tent sites; and so on. The second subproblem is the proliferation of undesired user-created campsites. This problem can occur at popular destinations where every "campable" site is disturbed because camping is not confined to a small number of frequently used campsites (Cole 1982a). It also occurs in little-used places, such as lake basins that have a number of moderately disturbed campsites, despite use levels so low that encounters between parties are highly unlikely. The importance of the factors affecting amount of impact and the recommendations for appropriate use differ between these two subproblems.

Deterioration of Established Campsites—On frequently used established campsites, loss of vegetation cover and soil disturbance are inevitable. The major "problems" occur where the disturbed area becomes extremely large, where trees are damaged unnecessarily, where campfire impacts are widespread, and where widespread erosion occurs. As mentioned earlier, the factors with the most influence on the severity of these problems are the type of camping party and the behavior of those campers. Enlargement is related primarily to party size and the presence of stock and occurs when too little attention is paid to

confining traffic to already impacted areas. Tree damage is a result of intentional damage, improper stock handling, and improper firewood selection. Campfire impacts result from lack of care in use of fire; erosion results primarily from selection of a site that is prone to erosion. Selection of a durable site is generally less important to avoiding deterioration of established sites than it is to avoiding site proliferation. It is most important to find a flat site with a ground surface that, before camping, would have been either unconsolidated mineral soil or thick organic horizons and, if possible, sparsely vegetated.

For hiking parties, the most important low-impact practices are:

Select a site that is large enough to accommodate your party (page 46).
Select a durable site (page 47).
Minimize intentional site alteration and the building of structures (page 50).
On established campsites, confine tents and activities to already impacted areas (page 52).
On established campsites, dismantle any structures you built and any other inappropriate structures; leave the site clean and attractive (page 53).
Limit the use of campfires where firewood is not plentiful (page 57).
In places with well-impacted campsites, build fires in existing firerings or on fire scars (page 61).
Gather firewood away from camp; disperse your gathering (page 63).
Use only dead and down firewood that you can break by hand (page 64).
Burn charcoal to ash; soak ashes; scatter excess firewood (page 68).
On preexisting fire sites, leave the firering clean and attractive; dismantle extra firerings (page 70).

All of these practices apply to parties with stock. In contrast to the practices designed to minimize trail problems, these practices are not more important for stock parties; however, the following practices are unique to parties with stock:

Use properly trained stock (page 78).
Minimize the number of stock (page 80).
Keep stock off campsites as much as possible (page 86).
Keep lengths of stay at one place short (page 87).
Use existing hitch rails and corrals where available (page 92).
Where confinement is necessary, use a hitch line on a durable site away from water (page 93).
Avoid tying stock to trees, particularly small trees (page 94).
Renovate pawed-up areas; scatter manure; remove picket pins and excess feed and salt (page 95).

Proliferation of Campsites—Creation of new campsites occurs whenever use of previously undisturbed sites exceeds very low levels. In popular places this occurs where visitors do not camp on sites that are already well impacted. This situation was documented in the Eagle Cap Wilderness where 221 campsites (more than half of which had suffered substantial vegetation loss) were found in a 325-acre area around two popular subalpine lakes (Cole 1982a). In remote, little-visited places, new campsites are created where visitors camp on sites that have already been disturbed and/or that are fragile, and where visitors are not careful to minimize impact and camouflage evidence of their stay. The magnitude of proliferation problems is influenced by frequency of use and site durability, as well as type of party and visitor behavior. Apparently undisturbed sites, without vegetation or with resistant vegetation, are preferred for campsites. Widespread dispersal of activities and traffic, as well as special care to minimize and camouflage disturbance, are also important. Large parties and parties with stock must use extra care, given their potential to cause rapid damage. Substantial off-trail use by parties unprepared to use extra care is likely to result in a proliferation of sites.

For hiking parties, the most important low-impact practices are:

Keep party size small (page 18).
Avoid off-trail travel unless prepared to use extra care (page 22).
In popular locations, select a well-impacted campsite (page 41).
In remote locations, select a previously unused campsite (page 42).
Never camp on a lightly impacted campsite (page 45).
Select a durable site (page 47).
Wear soft-soled shoes around camp (page 49).

Minimize intentional site alteration and the building of structures (page 50).
Avoid trampling vegetation (page 51).
On previously unused sites, disperse tents and activities (page 54).
On previously unused sites, keep lengths of stay short (page 55).
On previously unused sites, camouflage any disturbance (page 56).
Limit the use of campfires (page 57).
Build fires on mineral soil where trees, roots, vegetation, or rocks will not be scarred (page 60).
In places with well-impacted campsites, build fires in existing firerings or on fire scars (page 61).
In places without well-impacted campsites, do not use existing firerings or scars; dismantle any rings (page 62).
On previously unused fire sites, build fire in a shallow pit or on a mound of mineral soil (page 65).
Do not ring a fire with rocks (page 66).
Keep fires small (page 67).
Burn charcoal to ash; soak ashes; scatter excess firewood (page 68).
On preexisting fire sites, leave the firering clean and attractive; dismantle extra firerings (page 69).
On previously unused fire sites, remove all evidence of the fire (page 70).

All of these practices are important for parties with stock as well. Low-impact practices that are unique to parties with stock include:

Use properly trained stock (page 78).
Minimize the number of stock (page 80).
Keep lengths of stay at one place short (page 87).
Use existing hitch rails and corrals where available (page 92).
Where confinement is necessary, use a hitch rail on a durable site away from water (page 93).
Avoid tying stock to trees, particularly small trees (page 94).
Renovate pawed-up areas; scatter manure; remove picket pins and excess feed and salt (page 95).

Litter Problems

Litter is a common problem in wilderness and is one of the more important factors detracting from the experience of visitors. But it is perhaps the simplest problem to correct. It is the only problem that can conceivably be eliminated. Although a simple solution is not necessarily an easy solution, there is some evidence that litter problems have diminished in recent years (Lucas 1985).

Clearly, the cause of litter problems is improper disposal of items brought into the wilderness. The general policy of "pack-it-in, pack-it-out," if strictly followed, could eliminate littering. Several problems arise, even for conscientious visitors, however. Certain items (used toilet paper, leftover food scraps, and so on) are unpleasant to pack out. Other items are easily misplaced and left behind. This has prompted suggestions about items to bring or not to bring. An example might be packaging food in "zippered" plastic bags, rather than in bags with "twist-ties" that are easily left behind. Other problems result from attempting to burn items that will not burn (such as aluminum foil).

The few important low-impact practices relevant to this problem are:

Carry appropriate equipment (a trash bag) (page 16).
Pack out nonorganic litter (or burn readily burned litter) (page 71).
Pack out or burn organic garbage (or scatter fish viscera) (page 73).

All of these practices are important for parties with stock, as is the following additional practice:

Scatter manure; remove picket pins and excess feed and salt (page 95).

Crowding and Visitor Conflict

Interaction between parties is a frequently cited source of visitor dissatisfaction (Stankey and Schreyer 1987). As with campsite problems, the magnitude of crowding and conflict problems is influenced by the frequency of interaction, the types of parties encountered, the behavior of individuals in those parties, and the location of encounters (Manning 1986).

A basic assumption of wilderness management is that as interaction between wilderness visitors increases, opportunities for solitude and therefore the quality of the wilderness experience decrease. Research, however, has had surprising difficulty in showing a strong negative relationship between frequency of encounters and satisfaction. Stankey (1973, 1980) found a strong preference among wilderness visitors for low levels of contact, but responses were based on hypothetical encounter levels. In real wilderness situations, researchers have seldom been able to effectively isolate the effect of frequency of contact on the experience. It is clear that as interaction increases, opportunities for solitude (a critical goal of management) will tend to decrease; moreover, many visitors express the desire not to see "too many other people." Therefore, it is safe to conclude that high levels of interaction cause problems.

One of the reasons for the difficulty in finding a correlation between contact levels and satisfaction is the importance of variables other than frequency of contact. Mode of travel is one important mediating factor. Interactions between hiker and stock parties are more dissatisfying, particularly to the party of hikers, than interactions between similar parties (Stankey 1973). The same is true for contacts between parties using motorized and nonmotorized boats, a situation that occurs in portions of a few wilderness areas. A similar situation occurs in some contacts between parties traveling with and without dogs. Party size is another mediating factor. Stankey (1973) has also reported that visitors prefer seeing many small groups to a single large group.

In all of these cases, there is an asymmetrical relationship between two different types of party. Hikers, nonmotorized boaters, parties without dogs, and small parties are often disturbed by contact with their opposites, despite little reciprocal concern. The concerned parties apparently perceive the other type of use as inappropriate or undesirable and, consequently, conflict occurs when the parties interact. Conflict also results when any individual breaks someone else's norms of appropriate behavior and is observed in the act, or the consequences of that act are observed. Examples include raucous behavior, shooting guns, littering, or any other observable environmental impact.

Finally, the location of contacts can influence problem severity. Interaction between parties camped close to each other is generally more of a problem than contacts along the trail or elsewhere (Stankey and Schreyer 1987). Encounters that occur in more remote portions of the wilderness also tend to be more troubling than encounters close to the edge of the wilderness (Stankey 1973). This tendency, along with the fact that satisfaction is strongly related to expectations about number of encounters (Stankey and Schreyer 1987), suggests that visitors in little-used portions of the wilderness will have less tolerance for contacts than will visitors to popular places, regardless of proximity to trailheads.

It is possible to differentiate between problems resulting simply from meeting too many other people (too many encounters) and problems resulting from the type of encounter (conflict). The distinction is not always clearcut, and each subproblem aggravates the other. Visitors are likely to feel particularly crowded if many contacts are of a conflicting nature. Conversely, a perception of conflict is more likely if contacts are frequent. Nevertheless, the distinction is useful because certain low-impact practices are relevant to one or the other of the subproblems.

Too Many Encounters—The number of encounters judged to be "too many" differs between visitors and with a number of situational factors. Nevertheless, because many visitors desire low levels of interparty contact, the goal of low-impact practices should be to minimize interaction with other parties, particularly where they are camped and in remote and little-used portions of the wilderness. Interaction extends beyond mutual visual contact to include other people viewing you (and particularly your camp) without your knowledge and other people hearing you.

Perhaps more than for any other problem, it would be possible to carry attempts to minimize encounters to extremes. Encounters with others could always be minimized by never walking on trails or by never visiting places at times of the year when others do. The following low-impact practices can help minimize problems without requiring drastic changes in preferences and behavior:

Choose clothing and equipment colors that blend with surroundings (page 15).
Be quiet in the wilderness (page 24).
Take trailside breaks off trail on a durable site (page 35).
Select a concealed campsite away from trails, occupied campsites, lakes, and other water bodies (page 48).

Two other commonly suggested practices cannot be generally recommended because, in my view, their negative consequences may outweigh their positive benefits. Those practices are "visit wilderness during less popular days of the week and/or seasons" (see page 96) and "avoid visiting more popular places in the wilderness" (see page 97). Each of these practices, if successful, would decrease encounters in some places and at some times, but they would tend to increase encounters in other places and at other times. The times and places where and when encounters would increase are those where and when encounter levels are currently low. Although data are scanty and merely suggestive, these are the situations where visitors appear to be most intolerant of increased interaction with others. There certainly are situations in which the tradeoffs implicit in either of these practices suggest a positive benefit/cost ratio (an obvious example is any situation where even after the shift in use, no encounters occur), but these practices appear to be risky as general recommendations.

Visitor Conflicts—Although influenced by the number and location of encounters, the major factors that determine severity of conflict are the type of party encountered and the behavior of individual visitors. Hiking parties can minimize problems with the following low-impact practices:

Keep party size small (page 18).
Keep pets under restraint or leave them at home (page 23).
Be quiet in the wilderness (page 24).
Step off the trail, downslope, when encountering a stock party (page 36).

While these are the practices that will minimize face-to-face conflict, all of the practices to minimize litter, human waste, campsite, trail, and grazing area problems will also reduce conflict. These other impacts, if recognized, are signs of inappropriate behavior and therefore contribute to perceived conflict.

All of the stock-handling low-impact practices are important in that they will minimize the impacts caused by stock, impacts that many feel result from inappropriate use of wilderness. Practices with particularly direct abilities to reduce conflict are:

Minimize the number of stock (page 80).
Tie stock off trail, on a durable site, when taking a break (page 84).
Keep stock off campsites as much as possible (page 86).
Renovate pawed-up areas; scatter manure; remove picket pins and excess feed and salt (page 95).

Deterioration of Grazing Areas

Packstock cause substantial problems in some backcountry areas. They contribute to problems on trails and campsites, as well as crowding and visitor conflict. Practices important to minimizing these problems have already been listed. One additional impact unique to parties with stock is deterioration of grazing areas. Places where stock are confined and/or allowed to graze are altered by frequent defoliation of plants and by trampling. This causes cover loss, shifts in species composition, and loss of forage, and can result in destabilization of streambanks, lowering of water tables, and invasion of "weedy" species (DeBenedetti and Parsons 1979). This in turn can have adverse impacts on wildlife through competition for limited forage and reductions in forage production.

The effects of packstock grazing on natural ecosystems in wilderness are not well understood; neither are the factors that influence amount of deterioration. Results of range studies conducted elsewhere suggest that low to moderate levels of grazing may not cause adverse impacts, as long as stock are kept off fragile sites. One primary cause of severe deterioration is excessive grazing pressure. This can result from having too many animals, staying in one place too long, or not rotating stock frequently enough. This problem can be partially alleviated by packing in weed-free supplemental feed so there is less demand for limited forage. But even then trampling damage can be serious. The other primary cause is grazing of places that are particularly fragile or grazing at times of the year when fragility is high. Grazing of wet meadows and riparian strips, as well as grazing during times of year when soils are water saturated, can be particularly destructive.

This suggests the value of the following low-impact practices:

Avoid trips where and when soils are wet and muddy (page 20).
Use properly trained stock (page 78).
Minimize the number of stock (page 80).
Avoid places that have already been heavily grazed (page 85).
Keep lengths of stay at one place short (page 87).

Water stock downstream from drinking sources on a durable spot (page 88).
Carry an appropriate amount of weed-free supplemental feed (page 89).
Place feed and salt on a tarp or in a feedbag or container (page 90).
Minimize confinement of stock when grazing; move picketed stock frequently (page 91).
Renovate pawed-up areas; scatter manure; remove picket pins and excess feed and salt (page 95).

Human Waste

Human waste generally cannot be treated in a pack-it-in, pack-it-out manner, although this has become increasingly common on boating trips. Instead, it must be left in the wilderness. The presence of human waste in the wilderness is not a problem; problems result when other humans come into contact with waste, either directly or through drinking contaminated water. This suggests the obvious behavior necessary to minimizing impact—depositing feces away from lakes and streams, and places where others might come into contact with them. This latter constraint has not been considered a major problem because of the widespread belief that buried feces will decompose rapidly. Recent research in the Rocky Mountains found, however, that pathogenic organisms can survive in buried feces for a year or more (Temple and others 1982). Decomposition is not rapid. Therefore, it is important to bury human waste in places where it is unlikely to be uncovered for years.

Generally, human waste problems are serious only in destination areas where use is quite high and toilets are not provided. In these places, in addition to being careful to bury waste in a location away from water, it is important to walk a considerable distance away from campsites to find a burial site. Otherwise, there is a significant risk of contracting disease by unearthing feces with viable pathogens. In less popular places, widespread dispersal is less critical and in very remote places, surface disposal has even been recommended. This latter recommendation can be beneficial, particularly at high elevations where digging a hole can create an unnecessary disturbance that might take years to recover; however, the risk it presents in inappropriate situations makes it a controversial practice. Toilet paper, as with other nonorganic waste, should either be burned or packed out. Burial is a less desirable alternative—but accepted practice in many places.

Important low-impact practices are as follows:

Carry appropriate equipment (trowel) (page 16).
Pack out (or burn) nonorganic litter (toilet paper) (page 71).
Use toilets if provided (page 74).
Dispose of human waste in a properly located cathole (page 75).

Wildlife and Fishery Impacts

Although a number of case studies of recreational impacts on animals have been conducted (Boyle and Samson 1983), we lack an understanding of the prevalence or significance of impacts on animals or fisheries. There is also little understanding of the importance of factors that influence amount or type of impact; consequently, few specific recommendations about low-impact behavior can be made. This is clearly a critical information gap. Nevertheless, it is possible to speculate about some influential factors that are likely to be important.

Amount and frequency of disturbance are likely to be important. There are probably cases where occasional human intrusion would elicit little response, while frequent intrusion would cause displacement, nest abandonment, or some other undesired effect. But in a study of the effects of cross-country skiers on elk and moose, Ferguson and Keith (1982) found that movement occurred following the first encounter with humans; the passage of additional skiers caused no further disturbance. Some researchers have found that animals become habituated to human intrusion, making them less disturbed by human presence (Schultz and Bailey 1978). Others report more substantial disturbance of populations that have had more frequent encounters with humans. Although fewer encounters would generally be desirable, it is not clear what the aggregate effect of changes in the distribution of human use would be. Shifting more recreational use to places and seasons of the year that are currently little used certainly has the potential to increase problems.

Party characteristics appear unlikely to influence amount of disturbance substantially. Parties with packstock can compete with animals for limited forage in some places. Generally, however, the behavior of individuals is probably more important than characteristics of the party. For example, whether or not individuals engage in hunting or fishing can have a pronounced effect on disturbance; so can decisions about where to camp and one's care in approaching animals for a better view or a photograph.

Disturbance is more likely to occur at certain times of the year—for example, during birthing seasons or other times of stress. Disturbance is also more likely in some places than others. For example, human presence at desert waterholes will be much more disruptive than in places away from water.

Three distinct subproblems can be identified: (1) Unintentional harassment of animals, usually scaring them by approaching too closely or being some place they want to be. (2) Feeding animals or attracting them through improper camping techniques. This can cause adverse changes in feeding habits. (3) Competition with wildlife where excessive grazing occurs. (Hunting and fishing also cause disturbance; these intentional disturbances are not treated here.)

Animal Harassment—Disturbance of wildlife is most strongly related to user behavior and where and when disturbance occurs. Few specific practices can be suggested; the following suggestions are appropriate:

Avoid trips where and when animals are particularly vulnerable to disturbance (page 21).
Avoid off-trail travel unless prepared to use extra care (page 22).
Keep pets under restraint or leave them at home (page 23).
Avoid harassment of animals (page 27).
Select a campsite away from lakes and other water bodies (page 48).

Disturbance of Feeding Habits—The severity of this problem is related primarily to visitor behavior. Animals should not be fed anywhere. It is also important to protect food from animals and, particularly at campsites, to avoid attracting animals. Specific practices are:

Do not feed animals (page 28).
Protect food from animals (page 29).
Pack out or burn organic garbage (or scatter fish viscera) (page 73).

Competition—Competition with wildlife occurs only where there is excessive grazing of forage needed by wildlife. It is unclear how serious a problem this is. The factors that would likely influence problem severity include amount of grazing, grazing behavior, and where and when grazing occurs. Practices with the potential to minimize competition include:

Avoid off-trail travel unless prepared to use extra care (page 22).
Minimize the number of stock (page 80).
Keep lengths of stay at one place short (page 87).
Carry an appropriate amount of weed-free supplemental feed (page 89).

Water Pollution

Of all recreation-related management problems, water pollution is probably the least understood. We know little about the severity, prevalence, or even the nature of problems. Health hazards due to fecal contamination have been the primary concern. Studies that have attempted to quantify the incidence of fecal contamination and identify causal links to recreational use usually generate negative results. Bacterial contamination is seldom a problem (see, for example, Silverman and Erman 1979), and is often more problematic in places without recreational use because wild animals are the primary vectors of contamination (Stuart and others 1971). Contamination with *Giardia* spp. is a more common problem in wilderness. In the Sierra Nevada, Suk and others (1986) found *Giardia* cysts in 27 of 78 water samples, and cysts were particularly common in samples collected just downstream from popular campsites. Practices designed to mitigate this problem were discussed in the section on human waste. In addition, visitors are more often turning to water filtration or treatment to deal with the problem.

More insidious, and even less frequently documented, are more subtle changes in aquatic ecosystems. For the same lakes where bacterial contamination was not a common problem, Taylor and Erman (1979) documented changes in ion concentrations and aquatic flora and fauna. They speculated that these changes resulted from increases in the concentration of limited nutrients as a result of camping, bathing, washing, and other recreational activities close to the lakeshore. These changes, along with the changes related to stocking fish and angling, suggest that alteration of aquatic ecosystems may represent our greatest failure to "preserve natural conditions" in wilderness.

The primary influences on problem severity are related to where recreational activities occur. The most important low-impact practices are:

Select a campsite away from lakes and other water bodies (page 48).
Dispose of human waste in a properly located cathole (page 75).
Bathe, wash, and dispose of waste water away from water bodies (page 77).

Stock users should also practice the following:

Water stock downstream from drinking sources on a durable spot (page 88).
Where confinement is necessary, use a hitch line on a durable site away from water (page 93).

Other Problems

A few other practices do not apply to any of these specific problems, but relate to avoiding unnecessary disturbance of natural and cultural features. Important practices for all users include:

Minimize disturbance of natural features (page 25).
Do not disturb cultural artifacts or archeological sites (page 26).
Do not build a fire where fire danger is high (page 59).

RECOMMENDED LOW-IMPACT PRACTICES

In the sections that follow, recommended low-impact practices are described in detail. These are practices judged to be likely to contribute to minimizing impact problems. They have been grouped into seven categories. A complete list of recommended practices can be found in appendix A.

1. *Trip preparation*. Planning can be important to minimizing impact. Clothing and equipment are important (practices 1 and 2), as are party size (practice 3) and deciding where and when to visit (practice 4-6).
2. *General conduct*. Behavorial guidelines that apply at all times during a backcountry visit pertain to handling of pets (practice 7), noise levels (practice 8), disturbance of natural and cultural features (practices 9 and 10), and disturbance of animals (practices 11-13).
3. *Backcountry travel.* Appropriate practices when traveling in the backcountry differ between travel on existing trails (practices 14-18) and cross-country travel (practices 19-22).
4. *Campsite selection and behavior*. Camping practices pertain to both selection of a site and appropriate behavior once a site has been selected. Campsite selection criteria (practices 23-28) include level of previous impact, size of the site, durability, and location. Certain behaviorial practices apply to all campsites (practices 29-31). Some practices apply only when using well-established campsites (practices 32 and 33); others apply only when using previously unused sites (practices 34-36).
5. *Campfires*. Minimizing impacts associated with campfires begins with deciding whether or not a campfire is appropriate and, if it is, where it should be built (practices 37-42). Other practices pertain specifically to firewood selection and gathering practices (43 and 44), construction of a fire on a previously unused site (practices 45 and 46), and campfire use and cleanup (practices 47-50).
6. *Waste disposal and sanitation*. These practices apply to disposal of garbage (practices 51-53) and human waste (practices 54 and 55), as well as to proper methods of bathing and washing (practices 56 and 57).
7. *Additional practices for parties with stock*. Parties that travel with stock need to consider all of the preceding 57 practices. In addition, there are a number of additional practices of critical importance to minimizing impacts unique to stock parties. Specific practices pertain to equipment and trip preparation concerns (practices 58-60), practices when traveling on existing trails (practices 61-64), campsite selection (practice 65), campsite behavior (practices 66 and 67), watering, feeding, and grazing stock (practices 68-71), confining stock (practices 72-74), and cleanup (practices 75).

The treatment of each practice provides the following information:

Description—This section provides a short narrative description of the recommended behavior.

Sample Message(s)—One or more good examples from low-impact materials illustrate the practice. Numbers in parentheses allow ready reference to the materials listed in appendix B.

Problem(s) Addressed and Rationale—Problems are cross-referenced to those just discussed. More detail is provided on why the practice should minimize problems. Visitor commitment to low-impact practices is likely to be greater where the rationale behind recommendations is communicated to visitors.

Importance—This section provides an estimate of the importance of the recommended practice. Both the effectiveness of the practice in minimizing problems and the importance of problems are considered. Importance is judged high only where the practice is effective and the problem addressed is significant. Clearly, when developing a low-impact message, highest priority should be given to those practices that effectively minimize the most important problems.

Controversial Elements—For some practices, recommendations are controversial or inconsistent. Attempts to be overly specific or quantitative often result in inconsistency. Attempts to provide universally applicable recommendations, when practices are only appropriate in certain situations, also result in inconsistency. This section includes discussions of controversial and inconsistent elements and suggests means of minimizing controversy. This section does *not* refer to how controversial recommendations may be to visitors who might dislike a recommendation that is generally considered to be worthwhile.

Knowledge Needs—Information needs that would allow more effective application of the practice are described. This section spells out further information needed by researchers and managers, not information that needs to be transferred to visitors. Major research gaps are also highlighted in a subsequent section.

Frequency of Recommendation—How frequently each practice is recommended is estimated from the sample of source materials in appendix B. Very common practices are those recommended by at least 50 percent of the sources, while common practices are recommended by 20 to 50 percent of the sources. Uncommon practices are recommended in 5 to 20 percent of the sources. Rare practices are those that have been recommended, but by less than 5 percent of the sources.

Costs to Visitors—An estimate of the extent to which applying the practice is a burden to visitors. Time, effort, the extent of behavioral change required, and the number of visitors affected are all considered. Costs are highest where large numbers of visitors are asked to give up an activity for which there is no perceived substitute (for example, not having a campfire for esthetic purposes). Replacing large wall tents with small, lightweight tents is an example of a practice that is less costly because a reasonable substitute is available. Some comfort and convenience may be lost, but the function of keeping dry is retained.

Special Situations—This category is provided only for practices that are modified under certain circumstances.

Practices that have been recommended by some—but that may cause more problems than they correct—are described in a section on practices that can be counterproductive (see pages 96-99). The division into practices that are generally recommended and those that may be counterproductive, as well as the resolution of controversial elements are my opinions. These opinions are based on considerable research and experience as well as analysis of low-impact materials and widespread review of this report. These opinions are open to debate. Further research may suggest new ideas and practices and will undoubtedly increase the specificity and usefulness of recommendations.

Trip Preparation	PRACTICE 1—CHOOSE CLOTHING AND EQUIPMENT COLORS THAT BLEND WITH SURROUNDINGS
DESCRIPTION	The colors of clothes and equipment should be muted so that they are not visible from long distances.
SAMPLE MESSAGE	"To help you travel and camp inconspicuously, select dark-colored tents, clothing, and packs when you buy new gear. Earth-tone rusts, browns, and greens blend in best with the forest. Oranges, blues and other bright colors stand out like spotlights and contribute to a crowded feeling." (8)
PROBLEM ADDRESSED AND RATIONALE	Too many encounters. When visitors wear clothes and carry equipment in bright colors that contrast with surroundings, they are more likely to be observed. The more frequently visitors observe each other and their camps, the less solitude they feel. Therefore, selection of clothes and equipment in colors that blend with the surroundings can reduce the number of encounters and increase feelings of solitude.
IMPORTANCE	Moderate. Avoidance of bright colors is only a partial solution to crowding problems. It is much more useful in dealing with crowding problems at campsites and away from trails than with problems along the trail. Colors are less likely to help avoid an encounter along the trail, and visitors are less sensitive to encounters on trails than at campsites (Stankey 1973). This also suggests that brightly colored tents are the most serious problem. The color of equipment is also more important in places with long vistas (such as Alaskan tundra) than in places where visibility is limited (such as eastern forests).
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Common.
COSTS TO VISITORS	Low. The only loss to visitors is one of stylishness and brightness. On a gloomy day, a bright blue and yellow tent can add a little cheer. And perhaps a stylish red parka can make a person look or feel more attractive. But most of this is a matter of taste, which can be quite transitory. There is no significant cost in the form of decreased comfort, convenience, or impact on activity. Most safety concerns can be addressed by carrying some bright orange flagging and/or a mirror.
SPECIAL SITUATIONS	Major exceptions are the increased safety provided by bright equipment for winter camping (to improve visibility during inclement weather) and bright clothes during hunting season (to decrease the likelihood of being shot). Bright equipment during winter is not a problem because the likelihood of encounters is generally low. Bright equipment during hunting season is a problem that must be resolved by choosing safety (bright clothes) over reduced crowding.

PRACTICE 2—CARRY APPROPRIATE EQUIPMENT

DESCRIPTION

Certain equipment items can be helpful in reducing impacts. The most commonly suggested items are a small stove, a fire blanket, tents with poles and waterproof floors, trashbags, trowel, soft-soled shoes for around camp, hammock, and large water container. Items not to carry are more controversial. These items do not necessarily cause problems; they increase the potential for impact. Suggestions include cans and bottles, axes and saws, guns, lug-soled boots, radios and tape players, wire, and nails.

SAMPLE MESSAGES

"Carry a backpacking stove; stoves do not scar the landscape as campfires do. Repackage foods from boxes, bottles, and cans into plastic bags to save weight and space. Leave canned and bottled food home. Empty bottles, cans, and aluminum foil must be packed home. Take a trash bag or two to pack out your garbage—and litter that others may have left behind. A lightweight shovel, trowel, or ice axe will help you dispose of human waste." (8)

"Carry a collapsible water container to reduce the number of trips between water sources and your campsite." (86)

"Take lightweight soft shoes for around camp. Leave radios and tape players at home." (54)

"Leave your axe at home. They leave unnatural, unnecessary scars on trees and add weight to your pack. Seasoned users have found them to be unnecessary because of the abundance of downed wood." (58)

"Use a hammock for sleeping to minimize ground cover damage." (90)

PROBLEMS ADDRESSED AND RATIONALE

(1) Excessive campsite deterioration. Tents with poles and waterproof floors make it unnecessary to cut down trees for tent poles or to excavate a ditch around the tent. A portable stove makes a campfire unnecessary (Berger 1979), or at least reduces the dependence on local firewood supplies. Waterbags reduce the number of trips between campsite and water supply, minimizing the formation of undesired trails. Hammocks reduce ground cover damage, as may use of soft-soled shoes (Harlow 1977; Waterman and Waterman 1979). *Not* carrying axes and saws reduces the likelihood of scarring trees and logs around campsites. As long as fires are built with wood that can be broken by hand (practice 44), axes and saws are unnecessary for gathering firewood. Stock parties may want to carry these for clearing trail. (2) Litter. Carrying trashbags makes it easier to avoid littering and to pack out other people's litter. *Not* carrying food in cans, bottles, or even aluminum foil reduces the likelihood that these items will be left behind as litter. (3) Human waste. A trowel is useful in properly disposing of human waste. (4) Visitor conflict. *Not* bringing a radio or tape player reduces the chance that your noise will disturb others. A radio/tape player with earphones is another option.

IMPORTANCE

Ranges from high to low. Carrying a stove is probably most important. Use of a stove is critical to reducing the impacts of fire scars on campsites and the reduction of wood supplies around campsites. The other items make it more convenient to avoid causing impact.

CONTROVERSIAL ELEMENTS

None.

KNOWLEDGE NEEDS

None.

FREQUENCY OF RECOMMENDATION

Ranges from common for carrying a stove to rare for carrying a hammock and *not* carrying axes and saws.

COSTS TO VISITORS

Low. None of these items are either prohibitively expensive or heavy. The items *not* to bring will actually decrease weight. None of these substantially reduce convenience and some increase convenience. The proportion of visitors carrying gas stoves has increased dramatically in recent years (Lucas 1985) to where it is probable that a majority of overnight users carry a stove.

SPECIAL SITUATIONS

Rafts, and to a lesser extent canoes and kayaks, have the ability to carry specialized and often heavy equipment designed to minimize impact. The most common and important is a fire pan, a piece of equipment that minimizes the ecological impact of campfires and facilitates the disposal of charcoal and ash. A box for carrying out charcoal and ash further reduces the esthetic impact of campfires. Finally, portable toilets of varying degrees of sophistication have become an increasingly common means of dealing with problems of human waste at popular campsites (Hampton and Cole 1988). Information on how to acquire this equipment is available from agencies that manage many of the more popular whitewater rivers.

PRACTICE 3—KEEP PARTY SIZE SMALL

DESCRIPTION

Keep the number of people in your party as few as possible, but remember that visitors traveling alone take more risk.

SAMPLE MESSAGES

"Limit your party size. Large groups tend to have more impact than you would expect from increased numbers alone (for example, social trails developing between tent sites)." (42)

"Groups larger than 10 people traveling together are discouraged. This size wears out campsites by compacting soil, destroying ground cover, and using up available wood supplies, and their gregarious behavior tends to destroy the wilderness solitude of others visiting the area. Plan your trip with only a few companions." (45)

PROBLEMS ADDRESSED AND RATIONALE

(1) Excessive deterioration of campsites. Large parties require large campsites. Reducing party size would allow campsites to be smaller, provided that efforts are taken to rehabilitate and keep campers off peripheral parts of campsites (Marion and Sober 1987). (2) Proliferation of trails and campsites in little-used areas. Large parties will not necessarily cause more impact to established campsites large enough to accommodate the party; however, they will cause more rapid impact to previously undisturbed places (Hammitt and Cole 1987). Therefore, small parties are critical to avoid the creation of new campsites and trails in little-used places. (3) Visitor conflict. Encountering a large party has been shown to do more to diminish feelings of solitude than encountering the same number of people in small parties (Stankey 1973). This suggests that smaller party sizes would eliminate a potential source of visitor conflict. Large parties can reduce their impact by traveling and camping as several smaller groups and by avoiding places without constructed trails and well-established campsites (practice 6).

IMPORTANCE

Moderate. Should be very effective in reducing problems with dissatisfaction from encountering large groups, but its effects on ecological problems are likely to be less dramatic than many assume. The effectiveness of reduced party sizes in reducing resource damage is greatest where impact is likely to occur quickly (for example, in fragile areas, in little-used and relatively undisturbed areas, and where parties travel with stock). Limits on party size must be quite low (certainly no larger than 10) to be worthwhile. Current limits on party size—25 was the most common limit in 1980 (Washburne and Cole 1983)—are often so high as to be virtually meaningless.

CONTROVERSIAL ELEMENTS

Attempts to supply a specific recommended limit on party size have been widely divergent. Recommendations ranged from "4-6" to "less than 15." Aside from the general recommendation to keep party size small, the most common recommendation was "no more than 10." There is little basis for any recommendation beyond the general one to keep size as small as possible. Once a party exceeds a certain number (perhaps four to six), special care must be taken in off-trail travel, campsite selection, and avoidance of visitor conflict.

KNOWLEDGE NEEDS

Although not critical to evaluating the appropriateness of this suggestion, more information on the effects of various party sizes on the visitor experience and on resources would be useful. Research might be able to more precisely identify thresholds in group size that either result in perceived conflict between groups or that cause particularly rapid ecological impact. Such thresholds would certainly differ between backpackers and parties with stock. Of parties of the same size, those with stock would tend to cause more social and ecological impact.

FREQUENCY OF RECOMMENDATION

Common. Regulations limiting party size are also widespread (Washburne and Cole 1983).

COSTS TO VISITORS	Low for most parties. Median party size is usually about three; in nine western backcountry areas, only about 6 percent of parties were larger than 10 persons (Lucas 1980). Costs would be high for those parties who prefer or must travel in large groups (for example, outfitted or organized groups). Such costs could be reduced by condoning large parties, but recommending that they break up into small groups of four to six people to travel, that they disperse locally in camping areas and take care not to enlarge established sites, and that they use well-established routes and destinations.
SPECIAL SITUATIONS	In grizzly bear country it is safer to travel in groups of four or more. There is little advantage to a very large group, but parties of less than four are more likely to surprise a bear and less likely to repulse an attack (Hampton and Cole 1988; Herrero 1985).

PRACTICE 4—AVOID TRIPS WHERE AND WHEN SOILS ARE WET AND MUDDY

DESCRIPTION	Avoid visiting places during seasons when soils are water saturated. The season during and immediately after snowmelt is the most important time to avoid, particularly by parties with stock (Price 1985).
SAMPLE MESSAGES	"If trails are muddy following spring snowmelt, give them time to dry out before your trip. Then you will not have to wade through the mud and churn up the trail surface, making it rough for others to follow." (8) "If possible, plan your trip to avoid the wet soil conditions common early and late in the season." (12)
PROBLEMS ADDRESSED AND RATIONALE:	(1) Deterioration of trails, (2) creation of undesired trails, and (3) deterioration of grazing areas. Trails and meadows (or other places frequently trampled by stock) are particularly susceptible to deterioration when soils are water saturated (Cole 1987b). Constructed trails can be damaged easily and unwanted trails can develop spontaneously (fig.1A). The temporal distribution of wetness can be both unpredictable (as in the case of sporadic thunderstorms) and predictable (as in the case of the season immediately following snowmelt). Staying out of the wilderness during seasons when soils are predictably wet will reduce deterioration of trails and grazing areas. Certain places are more prone to these problems than others. This is particularly important when traveling with stock.
IMPORTANCE	Low to high. In places that are seasonally wet, but relatively durable at other times, avoiding use during wet seasons can reduce impact substantially. In places where wetness is prolonged or unpredictable, or where durability is low even when soils are dry, this practice is less important. It is most critical for stock parties in mountainous areas in the West.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	Improved information on unfavorable seasons, variation in seasonality from year to year, and places that are particularly prone to problems with seasonal wetness and communication of this information to users would make it easier for users to comply. At Sequoia and Kings Canyon National Parks, parties with stock are not allowed until after an opening date (when conditions have dried out) that varies with general climatic conditions for that year and with the specific places to be visited. Monitoring data have indicated where and when early season stock use is a problem. Opening dates are decided on well before the season starts, to give parties a chance to plan their trips (DeBenedetti and Parsons 1983). Similar programs of information and recommended opening dates could be implemented, relying on voluntary compliance rather than regulation.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Low to moderate. Most visitors will not have to alter their behavior because many areas do not have pronounced and predictable wet and dry seasons. Where wet and dry seasons are pronounced and predictable, most visitation occurs during dry seasons. Substantial costs are borne only by those who cannot shift trips to less-vulnerable seasons.

PRACTICE 5—AVOID TRIPS WHERE AND WHEN ANIMALS ARE PARTICULARLY VULNERABLE TO DISTURBANCE

DESCRIPTION	Avoid visiting places at times when animals are likely to be adversely affected by your visit (for example, when they are giving birth or are weak).
SAMPLE MESSAGE	None.
PROBLEMS ADDRESSED AND RATIONALE	Harassment of wildlife. Animals are particularly vulnerable to disturbance at certain times of the year (Ream 1979). For example, the consequences of fleeing, when scared by an approaching human, are often more pronounced during birthing season (when young may be left vulnerable to predation) and winter (when animals are already stressed and attempting to minimize unnecessary activity) than during midsummer.
IMPORTANCE	Uncertain. To the extent that harassment is a problem, this practice would be an effective means of minimizing problems. To evaluate importance, we need more information on the vulnerability of animals at different times of the year.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	Current knowledge is so poor that we are seldom able to provide specific behavioral suggestions. Consequently, this recommendation is of little practical value. We need to know more about impacts of recreationists on animals and seasonal differences in vulnerability. Many different animal types from varied regions and ecosystems should be studied.
FREQUENCY OF RECOMMENDATION	No examples were found.
COSTS TO VISITORS	Low to moderate. Most visitors will not have to alter their behavior. Costs may be most pronounced for cross-country skiers, where animals are particularly vulnerable during winter. Again, we need more information.

PRACTICE 6—AVOID OFF-TRAIL TRAVEL UNLESS PREPARED TO USE EXTRA CARE

DESCRIPTION	When traveling off trail, it is particularly important to take care to avoid impact. Route selection and traveling behavior (practices 19-22), and campsite selection and behavior (practices 27, 34-36) require more thought and time. Large parties and parties with stock should avoid off-trail travel unless they are willing to be extremely cautious. Traveling on trails will minimize all problems except excessive encounters and human waste.
SAMPLE MESSAGE	"The impacts associated with cross country travel are minimized when group size is small, routes are carefully selected to avoid fragile terrain and critical wildlife habitat and special care is taken to avoid disturbance." (30)
PROBLEMS ADDRESSED AND RATIONALE	(1) Development of undesired user-created trails. Constructed trails are already highly disturbed, and in many cases have been designed to accommodate heavy use. Leaving trails introduces the risk of creating undesired trails. The potential for this is minimized if parties are small, travel on foot, and select dispersed and durable routes. (2) Animal harassment. Off-trail travel, by accessing relatively undisturbed places, increases potential for disturbance of animals that have sought out remote places. (3) Proliferation of campsites. The potential for creation of new campsites is also high because off-trail travel provides access to relatively undisturbed places. Again, this simply means that special care is needed.
IMPORTANCE	High. If only those parties capable of and committed to practicing minimum impact visited off-trail areas, it would be possible to avoid problems in these places.
CONTROVERSIAL ELEMENTS	Some low-impact materials recommend that hikers avoid trails entirely. This seems unwise unless concern for avoiding visitor contact problems on trails is given a much higher priority than all other problems. Increased off-trail travel will increase contact in places where those encounters are likely to be much more disruptive than along trails.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Low. Most visitors choose to travel on trails and most visitors who do travel off trail are experienced and capable of minimizing their impact. Most costs are borne by large groups and parties with stock that wish to travel off trail but are not willing to exert the special care required. These visitor costs are low compared with the benefits of reduced impact, however.

General Conduct

PRACTICE 7—KEEP PETS UNDER RESTRAINT OR LEAVE THEM AT HOME

DESCRIPTION

Where pets are allowed (they are prohibited in all National Parks and in some backcountry areas managed by other agencies), they should be kept under vocal or physical restraint (leashed).

SAMPLE MESSAGES

"Keep dogs under control at all times; they disturb wildlife, hikers, and campers." (5)

"You may bring dogs into the BWCA, but respect other visitors' rights. Keep dogs on a leash while on portages and prevent excessive barking." (58)

PROBLEMS ADDRESSED AND RATIONALE

(1) Visitor conflict. Dogs can disturb other visitors (Waterman and Waterman 1979). Unrestrained dogs on trails can spook stock, creating problems. (2) Animal harassment. Unrestrained dogs can also chase and harass animals. These problems can be minimized by leaving highly aggressive dogs at home and keeping all dogs under restraint.

IMPORTANCE

Low to moderate. There is little evidence that pets are a major source of conflict or wildlife disturbance. Keeping them under restraint can effectively minimize problems that do occur. For many dogs, carrying a moderately heavy backpack is an effective means of controlling them on the trail. Restraint at campsites is most important where other parties are camped close by. This problem can be reduced by seeking out more isolated campsites when traveling with pets.

CONTROVERSIAL ELEMENTS

Recommendations that all pets be left at home are increasingly common. While this would be even more effective in eliminating this source of problems, it unnecessarily eliminates a traditional use of wilderness that many visitors value highly. The problems that result from travel with pets are minor compared with those that result from travel with stock, for example. Therefore, as with stock, it seems more appropriate to seek means of permitting use but reducing negative consequences. Pets are already prohibited in National Park wilderness.

KNOWLEDGE NEEDS

We need more information on visitor conflict related to pets and the significance of impacts on animals.

FREQUENCY OF RECOMMENDATION

Common.

COSTS TO VISITORS

Low. Visitors with pets must accept more responsibility for those pets. This may mean more time and effort restraining them, but these efforts need not be substantial. Using a dog backpack would lighten pack loads, and seeking out campsites away from other parties is generally recommended behavior anyway. Only those owners with highly aggressive animals that should be left at home must forgo anything. Even these owners will probably have a more enjoyable experience because they need not worry about conflict.

PRACTICE 8—BE QUIET IN THE WILDERNESS

DESCRIPTION	Avoid making loud noises, such as by yelling or playing recorded music.
SAMPLE MESSAGE	"Stay as quiet as possible and enjoy the quietness." (54)
PROBLEMS ADDRESSED AND RATIONALE:	(1) Too many encounters. Making loud noises makes it more likely that other parties will know you are there. This will tend to reduce solitude. (2) Visitor conflict. Of more importance, loud human noises are often considered to be inappropriate in wilderness. Encounters with parties acting in ways deemed to be inappropriate can lead to serious conflict and perceived crowding problems (Manning 1986).
IMPORTANCE	High. This behavior is less important where there are no other parties around; however, loud noises may also disturb wildlife.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Common.
COSTS TO VISITORS	Minimal.
SPECIAL SITUATIONS	The major exception to this practice is in areas with grizzly bears. There it is important to make noise, particularly while traveling, to alert bears to your presence. That gives them time to move away without confrontation (Hampton and Cole 1988; Herrero 1985).

PRACTICE 9—MINIMIZE DISTURBANCE OF NATURAL FEATURES

DESCRIPTION	Try to "leave things as they are." Avoid unearthing rocks, picking wildflowers, and cutting or uprooting trees and other plant life. Use restraint when gathering edible plants and animals to avoid long-term depletion.
SAMPLE MESSAGES	"Leave rocks and flowers where you find them so others can enjoy them as you do. Minimize disturbance of stones, soil, and plant life, so as not to disturb the conditions in which plants and animals live." (86) "Please do not dig up plants, pick wildflowers, or cut branches from live trees." (80) "Enjoy an occasional edible plant, but be careful not to deplete the surrounding vegetation or to disturb plants that are either rare or do not reproduce in abundance (such as many edible lilies)." (30)
PROBLEM ADDRESSED AND RATIONALE	This practice addresses concern with recreational impacts in general, without reference to any specific location such as trails or campsites. Disturbance is most concentrated along trails, around campsites, and at attraction sites.
IMPORTANCE	High. Although this practice is quite general, it is an attitude that is critical to avoidance of unnecessary disturbance.
CONTROVERSIAL ELEMENTS	Although this attitude is accepted in principle, it is not always applied to standing trees, both dead and alive, which are often cut down for tent poles or firewood.
KNOWLEDGE NEEDS	The vulnerability of edible plant and animal populations to harvesting is poorly understood. Information on species and places with high vulnerability is needed.
FREQUENCY OF RECOMMENDATION	Common.
COSTS TO VISITORS	Low. Some activities (picking wildflower bouquets, collecting edible plants) may be curtailed. Desired campsites may need to be bypassed if they require removal of rocks or vegetation. Parties may have to carry self-supporting tents and forgo the comfort of large wall tents; they may have to search further for downed firewood and reduce their wood consumption. But all of these inconveniences affect few users in small ways.

PRACTICE 10—DO NOT DISTURB CULTURAL ARTIFACTS OR ARCHEOLOGICAL SITES

DESCRIPTION	Historical and archeological sites should not be disturbed. Cultural artifacts should not be removed.
SAMPLE MESSAGE	"(Archaeological sites) are not renewable and cannot be replaced. Look, photograph, enjoy. But do not disturb. Climbing in, on or around ruins will speed up destruction of the site. Touching rock art will leave oils from your skin on the rock, these oils hasten the deterioration of the art work. Do not remove artifacts! Give someone else the chance to experience the thrill of discovery as you have. It is also against the law. Have respect and appreciation for the time and energy these ancient inhabitants put into their work. It has survived for hundreds of years. Help us preserve it for future generations." (74)
PROBLEM ADDRESSED AND RATIONALE	Maintenance of cultural and historical artifacts and sites.
IMPORTANCE	High. These practices are critical to the preservation of this element of heritage.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Low. The ability to explore sites may be inhibited, and visitors must resist the desire to remove artifacts. But these are relatively insignificant to the wilderness experience and necessary if others are to have similar opportunities.

PRACTICE 11—AVOID HARASSMENT OF ANIMALS

DESCRIPTION

Visitors should avoid approaching animals if it causes them to flee, particularly where this causes animals to abandon sites where they give birth or water sources, feeding grounds, or shelter, particularly when they are weak.

SAMPLE MESSAGES

"Observe animals from a distance—do not disturb." (86)

"Respect the needs of . . . animals for undisturbed territory. When tracking wildlife for a photograph or closer look, stay downwind, avoid sudden movement, and never chase or charge any animal. [Taking these precautions] is particularly important at birthing or nesting sites and at watering or feeding grounds, especially during times of year, such as winter, when animals are already stressed. Find out as much as you can, before entering the area about species, places and times when disturbance is likely." (30)

PROBLEM ADDRESSED AND RATIONALE

Harassment of animals. Numerous case studies have documented situations in which animals have been disturbed by the intrusion of recreationists. (For annotated bibliographies, see Boyle and Samson 1983; Bromley 1985; Ream 1980.) Birds can abandon nests, leaving eggs vulnerable to predation; large mammals forced to flee in winter can find it difficult to find food to replace lost calories. While these studies show that problems exist, we know little about how serious or prevalent these problems are.

IMPORTANCE

Uncertain. It is a truism that this general recommendation is an effective means of avoiding harassment. What is not clear is what specific behaviors are effective or where and when these behaviors are important. It is probable that only certain species are highly susceptible to disturbance and, even for these species, potential for disturbance is confined to certain critical habitats and seasons. But we do not know which species are vulnerable or when and where harassment is particularly damaging. One partial exception is bighorn sheep. Research has shown that bighorn sheep are more profoundly disturbed by hikers with dogs and hikers who approach from over a ridge than by those without dogs and those who remain below (MacArthur and others 1982). Thus, in bighorn country harassment can be reduced by not bringing dogs and by keeping to valley bottoms. More research into and presentation of information of this type is needed to make this practice effective.

CONTROVERSIAL ELEMENTS

None, except that we do not know enough to agree about where and when disturbance is a substantial problem and what sorts of behavior are most appropriate.

KNOWLEDGE NEEDS

For many, the presence of abundant wild animals is synonymous with high-quality wilderness. And yet, except for a few species such as the grizzly bear, we know nothing about how they react to recreationists. Information is inadequate on most aspects of recreation-wildlife encounters and appropriate behavior for minimizing disturbance. We need to learn about how serious impacts are; where and when they occur; the susceptibility of different species, at different seasons and places; and how amount, frequency, timing, and type of use, as well as visitor behavior, influence amount of impact. Moreover, because answers to these questions will be somewhat unique to each area, research must be conducted in a variety of places.

FREQUENCY OF RECOMMENDATION

Rare. Usually quite general (and of little practical value) when included at all.

COSTS TO VISITORS

Low to moderate. Most visitors will not have to alter their behavior. Costs include not visiting or not camping in certain critical places at certain critical times and not approaching animals to get a better view or a photograph. By carrying a telephoto lens and/or binoculars, visitors can view wildlife from a distance.

PRACTICE 12—DO NOT FEED ANIMALS

DESCRIPTION	Do not give animals food. This also applies to either accidentally or deliberately leaving food scraps behind (see practice 53).
SAMPLE MESSAGE	"Feeding wild animals produces numerous undesirable effects. It creates unnatural, unbalanced populations which become dependent on unnatural foods. This causes increased susceptibility to disease, and unnatural stresses within the population. Serious personal injury from the larger animals may result as they lose their fear of man. Please—help maintain a natural, balanced ecosystem—don't feed them." (86)
PROBLEM ADDRESSED AND RATIONALE	Disturbance of feeding habits. Feeding of animals can alter animal nutrition and behavior and, ultimately, population structure and distribution.
IMPORTANCE	Low to high, varying greatly between species. Not feeding animals is critical for species that tend to be attracted to and scavenge human food. For bears, feeding can cause behavioral changes that ultimately result in their having to be destroyed. For many other species, the effect of feeding on habits is negligible compared to other sources of disturbance.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon, except in the National Parks.
COSTS TO VISITORS	Low. Some enjoyment derived from feeding animals, such as squirrels and jays, must be forgone.

PRACTICE 13—PROTECT FOOD FROM ANIMALS

DESCRIPTION	Store food, either overnight or when away from camp, in such a way that animals cannot get it. Hanging food away from bears is particularly important.
SAMPLE MESSAGE	"Getting your week's supply of food ripped-off by a bear is bad enough. But if the bear should smell the raisins you have stashed in your sleeping bag, and you are also in the bag, you could get injured. In bear country the rule is: Hang all your food in a tree at night, at least 8 feet off the ground, and at least 4 feet out on a small limb. Then camp well away from the food." (14) Similar recommendations could be developed for other animals (such as rodents) that can get into food.
PROBLEM ADDRESSED AND RATIONALE	Disturbance of feeding habits. If animals develop an affinity for human food, their behavior and distribution change. When this happens with bears, problems can be particularly severe because problem bears frequently must be destroyed.
IMPORTANCE	Low to high, varying among species. Most animals are little affected by food storage techniques; however, for the grizzly bear, proper food storage may be critical to their survival.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon. Almost always confined to concern with bears.
COSTS TO VISITORS	Low. Some additional time and preparation are required, primarily for gathering together and hanging food. Research on an informational program on food storage techniques to reduce bear depredation at Yosemite National Park suggests that visitors have difficulty translating this knowledge into behavior. While 95 percent of visitors received a brochure on proper techniques, and 92 percent believed they were properly storing food, checks of actual behavior found only 3 percent storing their food properly (Graber 1986).

Backcountry Travel

PRACTICE 14—AVOID WALKING ON CLOSED TRAILS AND/OR DEVELOPING USER-CREATED TRAILS

DESCRIPTION

In places where undesired user-created trails are developing, or where trails have been closed to use, they should not be used. Either walk on open constructed trails or walk off trail some distance away from the developing or closed trails. This may be difficult in popular places where user-created trails are proliferating. Here it may be best to treat one trail as the officially sanctioned one and confine use to that trail.

SAMPLE MESSAGES

"[In areas without established trails] don't follow trampled paths." (86)

"Cross country travel is undesirable where user-created trail systems are developing . . ." (30)

"When you step off a trail make sure that you are the first to do so in that spot. If you can see the tracks of one other person, you will be contributing to trail cutting, erosion, and vegetation loss." (71)

PROBLEM ADDRESSED AND RATIONALE

Development of undesired trails. Low levels of trampling are capable of causing substantial impact (Bell and Bliss 1973; Cole 1985; and others). Therefore, incipient paths are likely to deteriorate quickly if use continues and closed trails will not recover if use continues (fig.1A).

IMPORTANCE

High. The primary cause of unwanted trails is too many people following the same route off trail. If developing and closed trails were strictly avoided, problems with trail proliferation would be minimal.

CONTROVERSIAL ELEMENTS

None.

KNOWLEDGE NEEDS

None.

FREQUENCY OF RECOMMENDATION

Rare.

COSTS TO VISITORS

Low to moderate. Places where user-created trails are developing, or established trails have been closed, are often attractive routes or destinations. Costs to visitors of having to avoid these areas can be reduced by providing access on established trails to the same or comparable places.

PRACTICE 15—WALK SINGLE FILE AND KEEP TO THE MAIN TREAD

DESCRIPTION

When following an existing trail, walk single file down the middle of the trail. Do not walk on the side of the trail. If there are several braids to the trail, stay to the main tread even if the footing is bad. Do not walk on developing parallel trail treads.

SAMPLE MESSAGES

"Walk single file in the center of the trail. Stay on main trail even if wet or snow-covered." (54)

"Always stay on the trail, even if it's wet and muddy. Don't step off to the side; that will create a new trail, which will soon become wet and muddy, so people will start stepping off to the side, cutting a new trail . . . . This is one of the prime causes of the multiple trails that create a freeway look in the backcountry." (25)

PROBLEM ADDRESSED AND RATIONALE

Deterioration of constructed trails. Where trails are muddy, snow covered, or deep and narrow, people are tempted to leave the main trail to find better footing. As illustrated in figure1B, this creates either a single wide tread or a stretch of multiple parallel trails (Price 1985). To avoid these problems, hikers and horseback riders need to resist the temptation to leave the main tread. They also should walk single file to minimize the lateral spread of traffic.

IMPORTANCE

Moderate. Trail widening and the development of multiple trails are two of the more common trail deterioration problems (Cole 1987b). They result entirely from lateral spread of trail use and therefore can be eliminated if hikers and stock users keep to the center of the established tread. This practice can eliminate these problems (and therefore must be considered highly effective); however, these problems are not among the most significant in wilderness, in that they do not substantially compromise either the integrity of wilderness ecosystems or the quality of wilderness experiences. More effective solutions to this problem, where trails are muddy or deep and narrow, are improved trail location and engineering (Price 1985).

CONTROVERSIAL ELEMENTS

None.

KNOWLEDGE NEEDS

None.

FREQUENCY OF RECOMMENDATION

Common.

COSTS TO VISITORS

Moderate. The primary costs are muddy boots and forgoing walking side by side. For stock users, the only cost is the effort and skill it takes to keep stock single file and on the muddy or narrow trail.

A

Figure 1—Trail problems and appropriate low-impact practices. (A) Meandering systems of user-created trails develop in popular destination areas. Avoid walking on either closed trails or developing user-created trails (practice 14). (B) Muddy trails that widen into quagmires and/or become systems of braided trails are a common problem. Important practices include avoiding trips where and when soils are wet and muddy (practice 4) and, if on a muddy trail, walking single file down the main tread (practice 15). (C) To reduce the likelihood of creating undesired user-created trails, cross-country hikers should spread out (practice 19). Hikers should not mark their route (practice 20) and should select a route that crosses durable surfaces (practice 21).

B

C

Figure 1 (Con.)

PRACTICE 16—DO NOT SHORTCUT SWITCHBACKS

DESCRIPTION	When approaching a trail switchback, stay on the trail. Do not follow a shorter route between trail levels.
SAMPLE MESSAGE	"Never short-cut switchbacks." (54) "Shortcutting switchbacks on steep trails damages soil and plants, leading to severe erosion problems. Switchbacks are designed and built into trails on steep terrain to minimize erosion and to conserve your energy as well." (86)
PROBLEM ADDRESSED AND RATIONALE	Deterioration of constructed trails. Shortcuts between switchbacks usually erode severely. This can also cause erosion of and deposition on the constructed trail.
IMPORTANCE	Moderate. This practice, if followed, would virtually eliminate the problem of erosion of switchbacks. This problem, however, is not one of the most serious in the backcountry. Therefore, the practice is highly effective, but probably not extremely important.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Very common.
COSTS TO VISITORS	Minimal. The frustration of a stretch of switchbacks is seldom alleviated by shortcutting them. Costs can be reduced through more careful design of switchback trails.

PRACTICE 17—TAKE TRAILSIDE BREAKS OFF TRAIL ON A DURABLE SITE

DESCRIPTION	When taking a break along the trail, move far enough off the trail so other parties can pass by without noticing you. Try to select a durable stopping point, such as a rock outcrop, a non-vegetated site, or a site with resistant vegetation.
SAMPLE MESSAGE	"When taking a break along the trail, move off the trail some distance to a durable stopping place. Here you can enjoy more natural surroundings and other parties can pass by without contact. Durable stopping places include rock outcrops, sand, other non-vegetated places and sites with durable vegetation, such as dry grasslands." (30)
PROBLEMS ADDRESSED AND RATIONALE	Too many encounters. Allowing other parties to pass without being aware of another party in the vicinity will increase perceived solitude. Selecting a durable stopping point will avoid unnecessary disturbance of natural features.
IMPORTANCE	Low to moderate. This practice will not eliminate problems with frequent trail encounters, but it can reduce them somewhat.
CONTROVERSIAL ELEMENTS	This action could lead to substantial off-trail disturbance if visitors are not careful to minimize disturbance at their stopping point.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Minimal. The cost of more time spent seeking an appropriate stopping point should be more than compensated for in the increased solitude and appreciation of the natural environment.

PRACTICE 18—STEP OFF THE TRAIL, DOWNSLOPE, WHEN ENCOUNTERING A STOCK PARTY

DESCRIPTION	To avoid spooking horses along a trail, hikers need to (1) move off the trail, (2) preferably on the downhill side, (3) avoid sudden movement, and (4) sometimes talk to the lead rider in a low voice. If you have a pet, make sure the animal is restrained and quiet.
SAMPLE MESSAGE	"Horses are easily spooked by strange sights and sounds. When hikers and riders meet along the trail, bucking horses and possible injuries to riders can be avoided if hikers will step off the downhill side of the trail, stand still, and speak softly until the horses pass." (8)
PROBLEM ADDRESSED AND RATIONALE	Visitor conflict. This behavior is a common courtesy extended by hikers to stock users. It avoids one source of conflict between these two groups.
IMPORTANCE	Moderate. This is another practice that is important in the sense of being a simple means of avoiding a problem for some users (those with stock that spook easily). It is not so important in the context of avoiding situations that seriously compromise overall wilderness objectives.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon (perhaps common in places with substantial amounts of stock use).
COSTS TO VISITORS	Minimal.

PRACTICE 19—SPREAD OUT WHEN WALKING OFF TRAIL

DESCRIPTION	When walking off trail, a group of people should spread out and not follow in each other's footsteps (fig. 1C). When selecting a cross-country route, select routes that permit people to spread out.
SAMPLE MESSAGE	"If you choose a route without trails . . . a group should spread out rather than walk one behind the other (especially in tundra or meadow areas). Ten people tramping in a row can crush plant tissue beyond recovery and create channels for erosion." (6)
PROBLEM ADDRESSED AND RATIONALE	Development of undesired user-created trails. Even infrequent trampling can destroy plants and create an incipient trail (see, for example, Cole 1985). Once recognizable, incipient trails attract additional use, and the end result is a pronounced trail. To avoid initiating this chain of events, it is important to minimize the number of times any plant is trampled. The key is for hikers to spread out. This will dilute the trampling impact of a group of people, hopefully enough to avoid damage. This is particularly important with a large party. Sometimes topography and vegetation tend to force single-file travel; such places should be avoided when selecting off-trail routes.
IMPORTANCE	Low to high. Importance varies with use levels and the priority placed on maintaining areas in a trailless condition. As use levels increase in trailless areas, spreading out and avoiding developing trails becomes increasingly important.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Low to moderate. Where terrain and vegetation are open and gentle, spreading out is easy. In other cases, however, there is a single path of least resistance. It can be difficult to avoid this route. Often such a route has already been affected by game traffic.

PRACTICE 20—DO NOT MARK CROSS-COUNTRY ROUTES

DESCRIPTION	When traveling off trail, do not mark the route with cairns, tree blazes, or in any other way. Let the next party find their own way.
SAMPLE MESSAGE	"Avoid leaving your mark (cairns or blazes) when bushwhacking or traveling cross-country. Leave it as undisturbed as possible, so that the next group will have the same experience of traveling through trail-less country." (23)
PROBLEM ADDRESSED AND RATIONALE	Development of undesired user-created trails. Where trails have not been constructed, spontaneous trail development should be discouraged. This requires minimizing use of cross-country routes. Blazing or marking routes will encourage further use of that route, leading ultimately to trail development. It also conflicts with objectives of minimizing unnecessary disturbance of natural features and evidence of human use.
IMPORTANCE	High. Maintaining trailless areas in wilderness is one of the more difficult challenges facing management. Marking of routes will eliminate any chance of avoiding trail development, except in places where use levels are negligible. Therefore, this practice is very important in maintaining the undisturbed qualities of trailless areas that are receiving use.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Minimal. The only conceivable cost is having to rediscover the route on a later trip.

PRACTICE 21—CHOOSE A CROSS-COUNTRY ROUTE THAT CROSSES DURABLE SURFACES

DESCRIPTION	When walking off trail, attempt to walk, as much as possible, on surfaces that will not be disturbed by trampling, such as nonvegetated surfaces, snow, or rock.
SAMPLE MESSAGE	"If you strike out away from trails, select rocky or hard ground or forested routes rather than meadows and wet places. Then, like the way of the Indians, your tracks will not be visible." (8) "[When traveling in areas without trails] walk on snow and rock where safe." (42) "If you wish to explore off-trail you are welcome to do so. Travel on slickrock and in dry washes leaves no trace of your passing." (71)
PROBLEM ADDRESSED AND RATIONALE	Development of undesired user-created trails. Durable surfaces can be walked over more frequently than fragile surfaces before an evident trail develops. The keys to avoiding trail development, then, are minimizing use frequency and maximizing surface durability. In general, surfaces that are dry, stable, and nonvegetated are most durable. Where off-trail routes keep to such surfaces as bare rock, ice and snow, sand- and gravel-covered riverbeds or washes, and nonvegetated forest floors, even moderate use can leave no trace. But relatively infrequent use of routes that cross steep and unstable slopes, moist and boggy areas, or places with lush and fragile vegetation will cause trail development. When considering appropriate routes through vegetation, both vegetation density and durability should be considered. Trails will develop more slowly in sparse vegetation, except where the plants that make up the cover are particularly fragile (a common situation underneath forest canopies). Some of the more durable vegetated types include those with virtually no ground cover, those with abundant large shrubs and little ground cover, and dry grasslands and meadows (Cole 1987b; Kuss 1986).
IMPORTANCE	Moderate to high. Importance increases with use level and the importance attached to maintaining trailless areas.
CONTROVERSIAL ELEMENTS	Specific recommendations about durable surfaces are frequently contradictory. This reflects inadequate knowledge about durability and attempts to make inappropriately broad generalizations. More research, more site-specific recommendations, and fewer broad generalizations are needed.
KNOWLEDGE NEEDS	We need more information, for specific places and environments, about the durability of different surfaces, particularly different vegetation types. This will permit the development of specific recommendations for individual areas.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Low to moderate. The principal costs are more time needed to select a durable route, as well as possibly avoiding more desirable routes because of fragility concerns. For many visitors these costs would be outweighed by the satisfaction of knowing that they have used their skills and knowledge to avoid creating a trail in an undisturbed area.

PRACTICE 22—USE CAUTION WHEN ASCENDING OR DESCENDING STEEP SLOPES

DESCRIPTION	When it is necessary to ascend or descend steep slopes off trail, special care is needed to avoid severe erosion. It is important to spread out and avoid developing trails, to switchback, to move slowly, and to avoid digging boots into the slope.
SAMPLE MESSAGE	"In mountainous areas, follow the backbones of gradual ridges instead of cutting down steep side slopes. If you must hike on a steep slope, make your own switchback as you ascend and descend. Do not glissade down gravel or scree slopes." (26)
PROBLEM ADDRESSED AND RATIONALE	Development of undesired user-created trails. Steep slopes are often particularly vulnerable to trail development (Weaver and others 1979). Therefore, it is important to minimize use and the impact caused by each hiker. Spreading out dilutes the trampling stress; moving slowly, switchbacking, and not digging boots into the slope reduce the impact of trampling.
IMPORTANCE	Moderate to high. Importance increases with use level. Where use is sufficient to result in trail development, this practice is critical to avoidance of severe erosion.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Low to moderate. It can be difficult to resist following a developing trail rather than spreading out. It also is often tempting to rapidly descend slopes, particularly where they are gravel and scree slopes.

Campsite Selection and Behavior

PRACTICE 23—IN POPULAR LOCATIONS, SELECT A WELL-IMPACTED CAMPSITE

DESCRIPTION

This recommendation applies to consistently used destination areas, as opposed to places where camping occurs infrequently. In such places, choose a campsite that already has experienced substantial impact (fig. 2B). Do not select a previously unused or lightly impacted site.

SAMPLE MESSAGE

"[In areas with trails and established campsites] camp in an established site so as to prevent the spread of bare areas." (86)

PROBLEM ADDRESSED AND RATIONALE

Proliferation of campsites. In places that receive consistent camping use, use of previously unused and lightly impacted sites is likely to lead to the creation and deterioration of new campsites. Sites that are already well impacted, if used with care, need not deteriorate substantially over time (Cole 1986a). Impacts are confined to these sites instead of being allowed to proliferate (Marion and Sober 1987).

IMPORTANCE

High. Not selecting sites that already are well impacted is the primary cause of ongoing campsite deterioration problems in popular destination areas (Cole 1986a). Moreover, this is among the most pervasive recreation management problems in wilderness (Washburne and Cole 1983). Therefore, it is of critical importance. Where not heeded, destination areas will be afflicted with numerous unnecessary and highly disturbed sites (see, for example, Cole 1982a).

CONTROVERSIAL ELEMENTS

Some have recommended that well-impacted campsites be avoided. While this recommendation is appropriate in remote places (see practice 24), it will cause widespread campsite impact in popular places. This is a case where what is appropriate in one situation is to be avoided in others. Attempts to make universal generalizations are counterproductive.

KNOWLEDGE NEEDS

Controversy about whether to use well-impacted or previously unused sites will not be resolved by research; it is a question of defining different situations in which each strategy is more appropriate. Research could perhaps help define more precisely the situations in which each strategy is appropriate.

FREQUENCY OF RECOMMENDATION

Common.

COSTS TO VISITORS

Low. Visitors must camp on sites that are already highly impacted. Most wilderness campers select such sites by habit (Cole 1982a; Heberlein and Dunwiddie 1979). Visitors who do prefer more pristine environments can simply visit more remote and little-used places.

PRACTICE 24—IN REMOTE LOCATIONS, SELECT A PREVIOUSLY UNUSED CAMPSITE

DESCRIPTION

When looking for a campsite in places away from trails or where camping occurs infrequently, select a site that shows no evidence of having been used before.

SAMPLE MESSAGE

"[When in areas without trails and established campsites] camp where there is no evidence that others have camped before." (86)

PROBLEM ADDRESSED AND RATIONALE

Proliferation of campsites. In places where overnight use is infrequent, careful use of durable sites need not cause disturbance (fig. 2A). The key idea behind this action is to minimize use frequency. If sites are not camped on after disturbance becomes evident, they should still be capable of recovering rapidly. Widespread dispersal and rotation of use between sites prevent any site from deteriorating substantially. For this strategy to be successful, however, use levels must be quite low. This action must also be accompanied by careful selection of a durable site (practice 27) and extra care in avoiding and camouflaging disturbance (practices 29-31, 34-36).

IMPORTANCE

High. This practice is critical to avoiding the development of established campsites in relatively undisturbed areas. It will be successful only when applied in places where use levels are low. In more popular areas, this practice is likely to result in proliferation of campsites (see, for example, Cole 1982a); in such places practice 23 (select a well-impacted campsite) is more appropriate.

CONTROVERSIAL ELEMENTS

Some low-impact materials recommend that all camping be confined to well-impacted campsites. While this recommendation is appropriate in popular places (see practice 23), it will cause unnecessary campsite impact in infrequently used places. This is a case where what is appropriate in one situation is to be avoided in others. Attempts to make universal generalizations are counterproductive.

KNOWLEDGE NEEDS

Controversy about whether to use well-impacted or previously unused sites will not be resolved by research; it is a question of defining different situations in which each strategy is more appropriate. Research could perhaps help define more precisely the situations in which each strategy is appropriate.

FREQUENCY OF RECOMMENDATION

Uncommon.

COSTS TO VISITORS

Low to moderate. Visitors must avoid obvious, established campsites. Presumably, most visitors in the more remote portions of the wilderness would value the less disturbed environment, but considerably more care in site selection and use is required. Those preferring traditional established campsites have the option of visiting more frequently used and heavily impacted places.

SPECIAL SITUATIONS

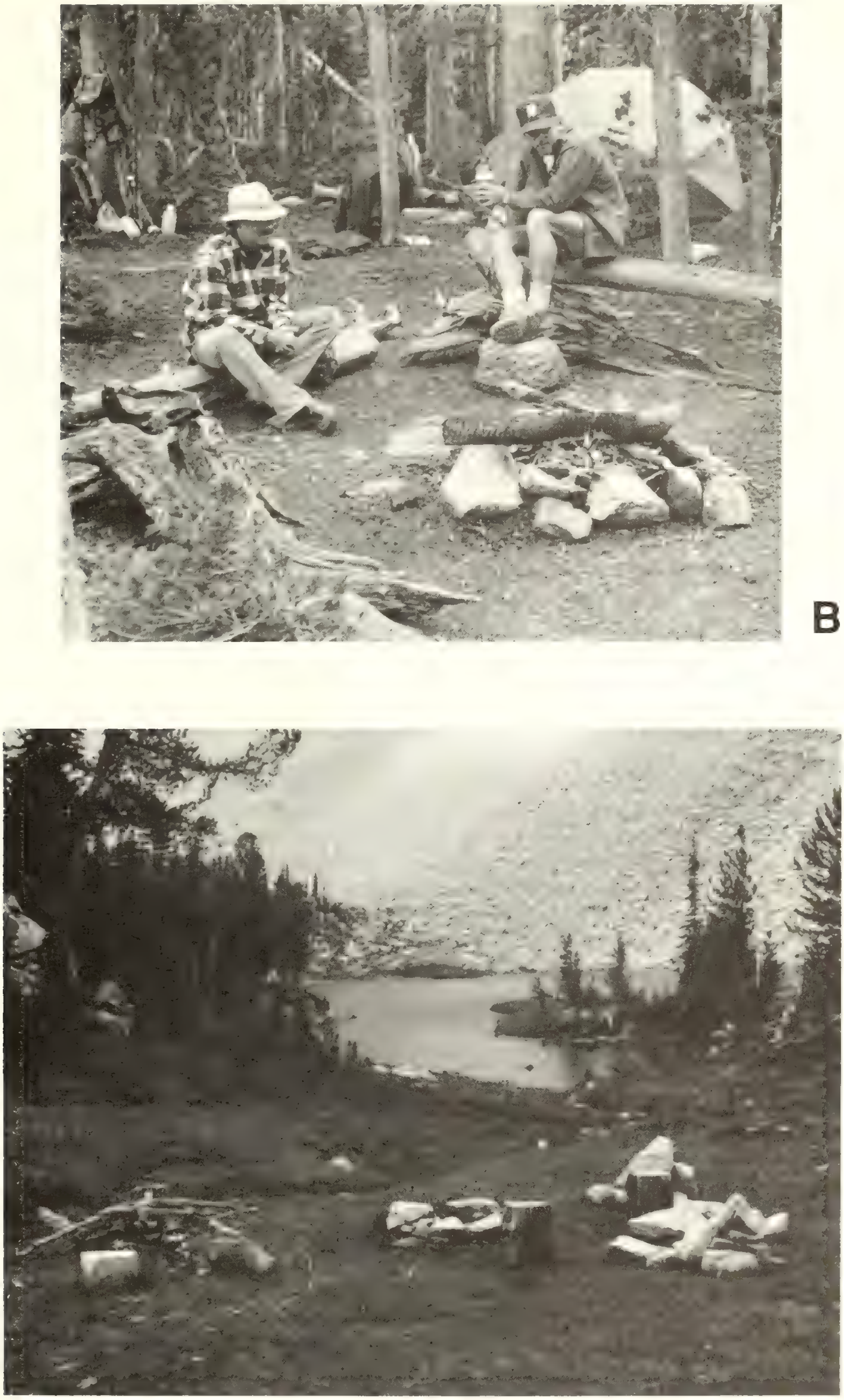
Many wilderness areas, particularly those managed by the National Park Service, prohibit camping except on designated campsites. One should always adhere to regulations of the managing agencies.

PRACTICE 25—NEVER CAMP ON A LIGHTLY IMPACTED CAMPSITE

DESCRIPTION	Avoid camping on an obviously disturbed but lightly impacted campsite (such as one in which there is obvious vegetation loss, but only on a small portion of the site [fig. 2C]). It is more appropriate to camp either on a more heavily impacted site (in popular places) or on a site with no evidence of use (in remote places).
SAMPLE MESSAGE	"Lightly impacted sites—those that have obviously been used but with a substantial amount of vegetation surviving on-site—should always be avoided; such sites will deteriorate rapidly with further use, while if unused they should recover rapidly." (30)
PROBLEM ADDRESSED AND RATIONALE	Proliferation of campsites. Lightly impacted campsites are on the verge of becoming permanent, well-impacted sites; continued use will cause this deterioration. If their use is curtailed, however, they still are capable of recovering. Therefore, it is better to camp on heavily impacted sites—where the most severe damage has already occurred—or on undisturbed sites that are capable of supporting infrequent use without deteriorating (Cole and Benedict 1983).
IMPORTANCE	High. This practice is critical to avoiding widespread campsite proliferation in popular destination areas and unnecessary campsite impact in relatively undisturbed places. In both situations there are more appropriate sites to select for camping.
CONTROVERSIAL ELEMENTS	Some low-impact materials suggest that visitors should select lightly impacted campsites. This recommendation appears to ignore the research findings that campsites at this stage of deterioration are most vulnerable to further deterioration with continued use (Cole 1987b).
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Low. More appropriate sites are always available.

A

Figure 2—Campsite impacts and appropriate low-impact practices. (A)In remote locations, it is most appropriate to camp on a previously unused site (practice 24). It is also important to select a durable site (practice 27), to spread out tents and activities (practice 34), to keep lengths of stay short (practice 35), and to camouflage any disturbance (practice 36). (B)In popular locations, it is most appropriate to camp on a well-impacted site (practice 23). It is also important to select a site that is large enough to accommodate your party (practice 26), to select a concealed campsite (practice 28), to confine tents and activities to already impacted areas (practice 32), and to leave the site clean and attractive for the next party (practice 33). (C) Lightly impacted sites, like this one, should not be used (practice 25). If the campfire ring is dismantled and the wood and rocks are scattered, this site should recover rapidly. With continued use, however, it will soon deteriorate into a well-impacted campsite.



B

C

Figure 2 (Con.)

PRACTICE 26—SELECT A SITE THAT IS LARGE ENOUGH TO ACCOMMODATE YOUR PARTY

DESCRIPTION

Select an established campsite with an already impacted area that is large enough for your party. It should be possible to locate the kitchen and all sleeping places in areas that are already highly disturbed. Select a larger site elsewhere, rather than risk enlarging the site by camping on its periphery.

SAMPLE MESSAGE

"Large parties and parties with packstock do the most damage and special efforts should be made to encourage them to select sites that already have been substantially altered and are large enough to accommodate their party size." (20)

PROBLEM ADDRESSED AND RATIONALE

Deterioration of established campsites. Most of the deterioration occurring on long-established campsites consists of the outward expansion of zones of impact (Cole 1986a; Merriam and others 1973). This occurs when parties camp on the periphery of sites, either because they choose to camp there or because they are too large for the site. The former cause can be alleviated by more carefully confining activities (see action 33); the latter cause is the one addressed by this action.

IMPORTANCE

Moderate to high. Site expansion is among the most serious campsite impact problems, and improper site selection is one of the causes of site expansion. But most parties naturally tend to seek out sites large enough to accommodate their group.

CONTROVERSIAL ELEMENTS

None.

KNOWLEDGE NEEDS

None.

FREQUENCY OF RECOMMENDATION

Rare.

COSTS TO VISITORS

Low to moderate. Most parties are small enough to be unaffected by this concern. Where campsites are few and far between, this practice may require traveling and searching more than a large party wants. This cost could be reduced by planning in advance to camp in places likely to have large campsites available. Managing agencies could also provide large parties with specific directions to suitably sized campsites.

PRACTICE 27—SELECT A DURABLE SITE

DESCRIPTION

Select a site that is durable enough so that your stay will not cause impact. Durability concerns differ between well-impacted sites and previously unused sites. Selecting a durable site is generally more important on unused sites; on well-impacted sites, the potential for damage has already been reduced by previous impact. Flat sites, without vegetation or easily disturbed soils, are always preferable. Selection of a site with durable vegetation is most important on previously unused sites. On well-impacted sites, vegetation will be lost regardless of durability; durable sites are those that have little erosion potential and have either thick organic horizons or unconsolidated mineral soil (Cole 1987a). Sleeping and cooking areas can be separated; cooking can be done on highly durable sites (such as rock slabs) that might be uncomfortable sleeping places.

SAMPLE MESSAGES

"Avoid locating campsites in areas that have delicate plants." (33)

"Choose a site on sandy terrain or the forest floor, rather than the lush, but delicate plant life of meadows, streambanks, fragile alpine tundra, and other areas that can be easily trampled or scarred." (6)

"Camp on snow or gravel rather than on vegetation; or select a site which is covered by dry sedge rather than heather, huckleberry or other less-resilient plants." (76)

PROBLEMS ADDRESSED AND RATIONALE

(1) Deterioration of established campsites. Well-established campsites in durable locations are less likely to experience excessive deterioration than those in fragile locations. The most common severe-impact problems related to site durability are erosion and exposure of highly compacted mineral soils; therefore, preferred sites include those with thick organic horizons and those in sand and gravel, with low erosion potential. (2) Proliferation of campsites. Durability is even more critical when selecting a previously unused site for camping. Durable sites can be camped on more frequently than sensitive sites before deterioration becomes obvious and additional users are attracted to the developing campsite. Vegetation loss is the most evident initial change on previously unused sites. Therefore, previously unused sites with a durable vegetation cover are preferred where it is not possible to select a site without vegetation.

IMPORTANCE

Moderate to high. This practice is extremely important on previously unused sites in places where use levels are not extremely low. It is among the most important means of avoiding the creation of new campsites. It is somewhat less critical either in very lightly used places or in places with well-established campsites.

CONTROVERSIAL ELEMENTS

The concept of using resistant sites is not disputed; what constitutes a durable site is controversial, however. Attempts to make broad generalizations, without recognizing differences between established and previously unused sites or between different environments, result in contradictory recommendations. Resolution of controversies will require additional research, as well as a willingness to recognize that this issue is complex.

KNOWLEDGE NEEDS

There is a sizable literature on site durability (see Cole 1987b and Kuss 1986 for an introduction). We need more information, however, for specific places and environments. This would permit the development of more specific recommendations such as those in sample message 76.

FREQUENCY OF RECOMMENDATION

Common. Many low-impact messages provide some do's and don'ts about durable places to camp. But there is little agreement on recommendations and less specificity than is desirable.

COSTS TO VISITORS

Low to moderate. The principal costs are the additional time required to search for a campsite that is resistant to impact, as well as desirable for other reasons, and forgoing camping on desirable sites that are fragile. For many visitors, these costs will be outweighed by the satisfaction of knowing that they have used their skills and knowledge to minimize impact. Moreover, many durable sites have characteristics that make them particularly desirable (for example, well-drained, rather than muddy or dusty).

PRACTICE 28—SELECT A CONCEALED CAMPSITE AWAY FROM TRAILS, OCCUPIED CAMPSITES, LAKES, AND OTHER WATER BODIES

DESCRIPTION

Locate your campsite where it is not likely to be observed by others walking or camping in the area. Locate it away from trails, occupied campsites, water bodies, and "beauty spots" that attract others. Concealed locations behind large boulders, in or behind clumps of trees, and on benches above lakes are ideal. In low-use places, this action is less important than selecting a durable campsite. In these places it may be preferable to select a durable open campsite instead of a more fragile forested site.

SAMPLE MESSAGES

"You will enjoy more solitude and be less conspicuous if you select a campsite away from the favorite spots. Locate your camp 200 feet or more from lakes, streams, meadows, and trails. Camping next to a busy trail or in full view of lakes, streams, and in meadows robs others of an unmarred scene and a feeling of solitude." (8)

"If other parties are close to where you want to camp, move on or choose your campsite so that terrain features ensure privacy. Trees, shrubs, or small hills will reduce noise substantially. Try to camp at least 200 feet away from water sources, trails, and 'beauty spots' to prevent water and visual pollution." (6)

PROBLEMS ADDRESSED AND RATIONALE

(1) Too many encounters. When selecting a campsite, it is important to locate a site where both ecological impacts and impacts on other campers are minimized. This action is primarily concerned with minimizing encounters between parties. By camping in places that are "out of the way," away from trails and other parties, and away from attractions, including lakes and other water bodies, contacts can be reduced (Echelberger and others 1983). They can also be reduced by selecting sites that are concealed by local topography and vegetation. (2) Animal harassment. In deserts, particularly, camping next to a waterhole can keep animals from water vital to their survival. (3) Water pollution. Arguments for locating campsites away from water bodies to avoid damaging fragile lakeshores and polluting water have intuitive appeal. There is little evidence, however, that lakeshores are particularly fragile (Cole 1982b) or that pollution from lakeshore camping is a serious problem (see, for example, Silverman and Erman 1979). There may be some places where camping close to water causes pronounced pollution. The primary justifiable rationale for asking people not to camp on lakeshores, however, is that this will tend to reduce encounters and preserve the esthetic qualities of lakeshores—a limited and highly valued resource (Cole 1981).

IMPORTANCE

Low to high. Importance varies with use levels and the nature of local topography and vegetation. In places where there are no other parties, this practice is not important (except where animals might be disturbed). In contrast, this practice is very important in destination areas with numerous parties. It can increase campsite solitude substantially, and campsite solitude is extremely important to many visitors (Manning 1986). It is also more important in environments with open vistas and few concealed sites.

CONTROVERSIAL ELEMENTS

There is little controversy about the recommendation. Some controversy exists about the rationale for recommendations not to camp on lakeshores. So far there is little definitive evidence that camping on lakeshores causes more serious or unique ecological impact problems than camping away from lakeshores. Unless this evidence can be found, it would be better to rely on social rationales that can be more easily justified.

KNOWLEDGE NEEDS

The value of this recommendation is based on the assumption that campers value campsite solitude more highly than they value being able to camp on traditional campsites close to trails and attractions such as lakes. This assumption is open to debate and could be tested. More research on water pollution adjacent to places where lakeshore campsites are located could resolve controversy over the underlying rationale for this recommendation.

FREQUENCY OF RECOMMENDATION

Very common. This is among the most common of recommendations.

COSTS TO VISITORS

Moderate. At first, costs could seem high because many campers will be forced to camp away from preferred campsites. Traditional campsites may have to be bypassed, with more time spent in campsite selection. But benefits in terms of campsite solitude should offset these costs, perhaps creating new norms for preferred campsite locations.

PRACTICE 29—WEAR SOFT-SOLED SHOES AROUND CAMP

DESCRIPTION	When you arrive at camp, take off lug-soled boots and put on soft-soled shoes such as tennis shoes or moccasins.
SAMPLE MESSAGE	"Wear sneakers or moccasins in and around the campsite. Heavy-soled shoes have a great impact on the ground cover. Besides, your feet deserve the rest." (90)
PROBLEMS ADDRESSED AND RATIONALE	(1) Deterioration of established campsites and (2) proliferation of campsites. Wearing soft shoes around camp may reduce deterioration both of established and previously unused campsites, if these shoes have less impact on vegetation and soil.
IMPORTANCE	Low. All studies to date have found little difference in the impact caused by different types of shoes (Kuss 1983; Saunders and others 1980; Whittaker 1978). Although there may be differences in some situations, they are unlikely to be substantial.
CONTROVERSIAL ELEMENTS	Although there is no controversy, the common belief that soft shoes are less damaging than lug-soled boots is not supported by research. But because costs to visitors are low, there are no likely ecological side-effects, and there may be some situations where consequences are beneficial, the recommendation to wear soft shoes can be supported.
KNOWLEDGE NEEDS	More research on the effects of different shoe types might identify situations where types differ in their impact. It might also more precisely define the importance of this practice.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Low. Soft shoes add weight and take up space, but not much. Having a change of shoes also offers advantages of comfort and safety.

PRACTICE 30—MINIMIZE INTENTIONAL SITE ALTERATION AND THE BUILDING OF STRUCTURES

DESCRIPTION

Avoid intentionally altering the campsite and building structures. Activities to avoid include moving rocks and logs, digging up vegetation, digging ditches around tents, and building such structures as tables, chairs, and hitch rails. If you do some landscaping and construction, be prepared to dismantle and camouflage it (actions 33 and 36). Never leave wire and nails.

SAMPLE MESSAGES

"Campcraft (rock wind screens, wood construction, trench lines around tents, etc.) is not only unnecessary, but it is also extremely destructive. Pick a well-drained campsite and use a tent with waterproof floor or a waterproof groundcloth so trenching won't be necessary." (86)

"Avoid trenching around your tent, cutting live branches, or pulling up plants to make a parklike campsite. If you do end up clearing the sleeping area of twigs or pinecones, scatter these items back over the campsite before you leave." (6)

PROBLEMS ADDRESSED AND RATIONALE

(1) Deterioration of established campsites and (2) proliferation of campsites. Engineering, landscaping, and construction of structures cause unnecessary impact to campsites, whether they are well established or virtually unused. These actions can cause further impact (such as where ditching causes accelerated erosion), they create eyesores and unnecessary evidence of human alteration, and on lightly used sites they can encourage increased use, which ultimately leads to campsite proliferation.

IMPORTANCE

Moderate. These impacts, while highly obtrusive, are generally not irreversible. This practice could, however, eliminate an entire category of unnecessary impacts.

CONTROVERSIAL ELEMENTS

There is some difference of opinion among users over the appropriateness of building facilities. While some users like to construct structures of various kinds, most wilderness users prefer primitive campsites (Stankey and Schreyer 1987); constructed facilities are major sources of visitor dissatisfaction (Lee 1975). There is little controversy, however, over the conclusion that these activities should be minimized in wilderness.

KNOWLEDGE NEEDS

None.

FREQUENCY OF RECOMMENDATION

Very common.

COSTS TO VISITORS

Low. Landscaping and construction may offer some additional comfort and convenience, but they are unnecessary.

PRACTICE 31—AVOID TRAMPLING VEGETATION

DESCRIPTION	When walking around on or sitting in the campsite, note surviving clumps of vegetation and avoid disturbing them. Avoid trampling tree seedlings in particular. Walking routes and the location of tents or kitchen areas can be adjusted to make it easier to stay off surviving vegetation (see action 32 as well).
SAMPLE MESSAGE	". . . watch where you walk to avoid crushing vegetation." ". . . try not to step on tree seedlings." (30)
PROBLEMS ADDRESSED AND RATIONALE	(1) Deterioration of established campsites and (2) proliferation of campsites. Where vegetation is sparse, either naturally or as a result of previous impact, vegetation loss can be minimized by being careful to step between rather than on plants. Survival of tree seedlings is critical to the long-term maintenance of forested campsites. Tree seedlings are quickly eliminated by trampling; therefore, special attention must be given to not stepping on them.
IMPORTANCE	Moderate. Efforts to not step on vegetation can be helpful in many situations, but where use is heavy or vegetation is dense, benefits are limited. This practice is most important (1) on previously unused sites where the vegetation is sparse and not highly resistant and (2) on established sites where tree seedling survival is limited.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Low. Some concentration is required at first, but soon watching where you step requires little thought. The location and nature of activities are unaffected.

PRACTICE 32—ON ESTABLISHED CAMPSITES, CONFINE TENTS AND ACTIVITIES TO ALREADY IMPACTED AREAS

DESCRIPTION	Locate tents and a central kitchen area in places that have already lost their vegetational cover. The general idea is to confine trampling, as much as possible, to places that have already been highly disturbed by trampling (fig. 2B).
SAMPLE MESSAGE	"When you camp at a well-marked site, you try to make most use of the ground that is already bare, already stamped by human presence; a little more traffic won't alter it further. When paths and pads are there, use them. But avoid doing anything to extend the barren area." (1)
PROBLEM ADDRESSED AND RATIONALE	Deterioration of established campsites. Expansion of zones of disturbance is the most common long-term deterioration problem on backcountry campsites (Cole 1986a). This practice seeks to avoid expansion by concentrating use on already impacted portions of the site. Onsite concentration complements the strategy of selecting an already impacted site, as opposed to an undisturbed site.
IMPORTANCE	High. Well-impacted campsites are undesirable to many wilderness users. In popular places they are inevitable. Impact levels on established campsites should be kept to a minimum, however. Avoiding expansion is perhaps the most important means of limiting deterioration, and onsite concentration of activities is critical to avoiding expansion of impact.
CONTROVERSIAL ELEMENTS	On previously unused sites, the opposing strategy—dispersing tents and activities—is more appropriate (practice 34). Attempts to make simple generalizations about traffic flow and activity location on campsites that apply everywhere are inevitably contradictory. The general concept of concentrating use in already disturbed places and dispersing use in undisturbed places should not be controversial.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Low. Assuming that a large enough (practice 26) well-impacted (practice 23) campsite has been selected, it should be a simple matter to confine activities to already disturbed portions of the site. This is probably almost instinctive behavior.

PRACTICE 33—ON ESTABLISHED CAMPSITES, DISMANTLE ANY STRUCTURES YOU BUILT AND ANY OTHER INAPPROPRIATE STRUCTURES; LEAVE THE SITE CLEAN AND ATTRACTIVE

DESCRIPTION	Dismantle any structures that were built. (As noted in practice 30, such construction should generally be avoided.) Structures built by others should also be dismantled, if they are inappropriate and not likely to be immediately rebuilt. Leave a single firering (but dismantle any additional rings) and any agency-built structures. Primitive log seats should probably also be left, and there are situations where user-built stock facilities should be left. The basic philosophy is to keep facilities to a minimum, but to avoid having them rebuilt on different parts of the site, spreading impact around. This requires striking a balance between the ideal goal of having no "permanent" facilities and the practical value of confining the impact associated with a facility to a small area. It is also important to leave the site clean and attractive so that other parties will be attracted to the site, rather than use some less appropriate site.
SAMPLE MESSAGE	"When leaving camp, make sure that it is clean, attractive and will be appealing to the next group to use the area .... It is appropriate to ... dismantle inappropriate user-built facilities, such as multiple firerings, constructed seats, tables, etc. However, properly-located and legal facilities, such as a single firering in many areas, should be left. Dismantling them will cause additional impact, because they will be rebuilt, with new rocks, and impact a new area." (30)
PROBLEM ADDRESSED AND RATIONALE	Deterioration of established campsites. The basic idea is to leave the campsite as attractive as possible so that other parties will want to camp on the site. This encourages concentration of use and impact. Therefore, it is important to (1) remove facilities that are considered inappropriate by others, but leave those that will certainly be rebuilt (primarily a rock firering and perhaps a sitting log) and (2) clean up the site, particularly pick up litter (practices 51 and 53) and clean up the firering (practice 49). Most visitors find a simple rock firering to be a desirable feature of an established campsite (Stankey and Schreyer 1987).
IMPORTANCE	Moderate. This practice effectively reduces impact, but those impacts are not irreversible.
CONTROVERSIAL ELEMENTS	Some people suggest that all facilities should be dismantled, regardless of the circumstances. This suggestion seems counterproductive where facilities will simply be rebuilt and impact a larger portion of the site. Stock facilities are particularly controversial. They are unnecessary, suggesting that they should be dismantled; however, the fact that they are frequently rebuilt suggests that it might be better to leave them. Perhaps dismantling of such facilities should be left to agency personnel.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Low. The time spent dismantling facilities and cleaning up the site, the primary cost, should not be great and will be offset by having clean and attractive sites to camp on.

PRACTICE 34—ON PREVIOUSLY UNUSED SITES, DISPERSE TENTS AND ACTIVITIES

DESCRIPTION

Set tents up some distance from each other and from the central kitchen area. Stay off the site as much as possible and disperse your activities. Take alternate paths to water and minimize the number of trips. A portable water container makes this easier. Do everything possible to minimize the number of times that any place or path is trampled. This practice, the opposite of practice 32—the appropriate behavior on well-impacted sites—complements the strategy of selecting previously unused sites in remote places.

SAMPLE MESSAGES

"If you are at a pristine site, most especially if there is vegetation underfoot . . . try to avoid repeated traffic over any one piece of ground. In moving between kitchen and spring, or tent and toilet area, take a slightly different route each time, and try to walk on duff, rocks, and mineral soils. Try not to mill around too much in one place, as at the entrance of the tent or in the cooking area." (1)

"Arrange your site to avoid concentrating activities in the cooking area. Carry water to your site in large containers so fewer trips are needed. Further reduce your impact by choosing a different route each time you go for water." (90)

PROBLEM ADDRESSED AND RATIONALE

Proliferation of campsites. To avoid creation of a campsite, it is important to minimize the number of times any piece of ground is trampled. Spreading out tents, activities, and traffic routes, along with selection of a previously unused site, helps realize this goal. Even a large party can avoid causing substantial impact if they locate their tents some distance from each other and avoid congregating in one place (unless that place is highly resistant—such as bare rock).

IMPORTANCE

Low to high. Where camping occurs on a virtually indestructable surface (such as bare rock, snow, or a beach), this practice is of little concern. It becomes increasingly important, however, as site durability decreases and as use levels increase.

CONTROVERSIAL ELEMENTS

On well-impacted sites, the opposing strategy—confining tents and activities to already impacted portions of the site—is more appropriate (practice 32). Attempts to make simple generalizations about traffic flow and activity location on campsites that apply everywhere are inevitably contradictory. The general concept of concentrating use in already disturbed places and dispersing use in undisturbed places should not be controversial.

KNOWLEDGE NEEDS

None.

FREQUENCY OF RECOMMENDATION

Uncommon.

COSTS TO VISITORS

Low. More attention needs to be paid to where you walk. This is part of the reason that using remote places and previously unused sites requires more care than using popular, well-impacted campsites and places. With time, this requires little thought, and this practice does not require significant changes in locations or behavior.

PRACTICE 35—ON PREVIOUSLY UNUSED SITES, KEEP LENGTHS OF STAY SHORT

DESCRIPTION	Minimize the amount of time spent on the site. In many situations, sites should not be camped on more than 1 night. Never stay so long that disturbance is pronounced.
SAMPLE MESSAGE	"Spend no more than a night or two at any site, to give plants a chance to recover." (86)
PROBLEM ADDRESSED AND RATIONALE	Proliferation of campsites. This practice, along with practices 24 (in remote locations, select a previously unused campsite) and 34 (spread out tents and activities), works to minimize the number of times any single piece of ground is trampled. This will limit deterioration and the likelihood that a campsite will develop.
IMPORTANCE	High. It is important that previously unused sites are not used for too many nights in a row. If they are, damage will be evident and further use is likely to be attracted to the site. Keeping lengths of stay to an absolute minimum may be less important, particularly where use levels are very low and sites are highly durable.
CONTROVERSIAL ELEMENTS	The concept is not controversial; however, there have been some inevitable contradictions in attempts to state exactly how many nights of use is acceptable. This maximum will vary with use frequency and site durability. Most low-impact materials suggest that lengths of stay should be limited on established campsites, as well as on previously unused sites. This is not necessary as long as other low-impact practices are followed (traffic is confined to devegetated places and site engineering and facility construction are avoided).
KNOWLEDGE NEEDS	More helpful information on appropriate lengths of stay could be provided if we had more research on deterioration rates of previously unused campsites. Such rates will vary with environmental characteristics, however, making a simple universally applicable limit an impossibility.
FREQUENCY OF RECOMMENDATION	Uncommon. Moreover, most recommendations have been applied to established campsites where this action is less important.
COSTS TO VISITORS	Moderate. This can require more frequent moving than desired. This is one of the costs of the extra care required to visit remote areas. Sometimes costs can be reduced by moving, but staying in the general area.

PRACTICE 36—ON PREVIOUSLY UNUSED SITES, CAMOUFLAGE ANY DISTURBANCE

DESCRIPTION	Make every effort to camouflage any inadvertent disturbance. Twigs, cones, and duff can be scattered on places where organic horizons have been scuffed up. Broken vegetation can be picked up and scattered elsewhere, while flattened vegetation can sometimes be "fluffed up." Fire sites in particular should be carefully camouflaged (action 50).
SAMPLE MESSAGE	"Before leaving camp, naturalize the area. Replace rocks and wood used; scatter needles, leaves and twigs on the campsite." (34)
PROBLEM ADDRESSED AND RATIONALE	Proliferation of campsites. Camouflaging disturbance is a way to avoid encouraging further use of the site. Any evidence that a place has been used as a campsite seems to attract repeat use. This practice is intended to minimize evidence of use.
IMPORTANCE	Moderate. Camouflaging disturbance is important; however, if other low-impact practices were followed, there should be little camouflaging required.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Low. Some time must be spent, but not much. This is another of the costs associated with use of remote places.

Campfires

PRACTICE 37—LIMIT THE USE OF CAMPFIRES

DESCRIPTION

Always question whether or not you really need or want a campfire. It is almost always better to cook on a stove, and esthetic fires are often not needed every night or can be limited to a short period of time. Work toward reducing the frequency and duration of campfires.

SAMPLE MESSAGES

"Fires should be used sparingly, as they are among the most serious visual impacts in the backcountry. Use of stoves is always preferable to building a campfire. Always carry a stove; use it for most if not all cooking; and only build a fire where it is safe and will not cause further damage or deplete wood supplies." (30)

"If possible, avoid building fires. For cooking, a stove is much easier and is far more efficient. Proper equipment, clothing and technique will provide more warmth than a fire. Fires are inadvisable because they sterilize the soil and inhibit growth. They remove materials that continue the decomposition/rejuvenation process and can destroy ground cover. In addition, fires create an artificial barrier between you and the sights, sounds, and smells of the outdoor environment." (23)

PROBLEMS ADDRESSED AND RATIONALE

(1) Deterioration of established campsites and (2) proliferation of campsites. The rationale behind this recommendation is to minimize the impacts associated with gathering firewood and having a campfire. Fewer and shorter fires, whether on well-impacted sites or on previously unused sites, will cause less impact. There will be less visual impact, less reduction of wood supplies, and less impact to the ground around an established fire site.

IMPORTANCE

Moderate. If all other low-impact recommendations on the use of campfires were followed, this recommendation would be unnecessary. This practice is most important (1) where proper fire location, construction, and cleanup practices are not followed and (2) in popular places, where firewood supplies have been depleted (places where fires would not be built if practice 38 was adhered to).

CONTROVERSIAL ELEMENTS

None.

KNOWLEDGE NEEDS

Nothing critical to the basic concept behind this recommendation. A better understanding of the significance of impacts associated with the gathering and burning of wood would improve our perspective on the importance of this action.

FREQUENCY OF RECOMMENDATION

Very common.

COSTS TO VISITORS

Low to moderate. As stated, costs are low. More emphatic statements about avoiding having campfires entirely are much more costly to those who enjoy campfires.

PRACTICE 38—AVOID FIRES WHERE FIREWOOD IS NOT PLENTIFUL

DESCRIPTION	Do not have a campfire in places where little dead and downed wood is available. Lack of firewood can reflect either low natural productivity (for example, close to and above timberline or in deserts) or depletion of wood supplies in popular camping areas. Either camp someplace where firewood is more plentiful or forgo a campfire.
SAMPLE MESSAGE	"You should use a campfire infrequently and only when there is abundant dead wood available on the ground. Be very critical about the necessity for campfires. In many areas, wood is being used faster than it grows. In overcamped areas or near timberline, choose an alternate campsite or use a portable stove." (6)
PROBLEMS ADDRESSED AND RATIONALE	(1) Deterioration of campsites and (2) general disturbance of natural conditions. Gathering wood in places where it is not abundant upsets ecosystem functioning around campsites. Large decaying wood in particular plays an important and irreplaceable role in the ecosystem—in water and nutrient conservation and as a substrate for biological activity (Cole and Dalle-Molle 1982). Where gathering of firewood depletes all the downed wood, even large pieces, impact becomes severe. This is a particular problem at timberline and in arid environment, where growth rates are slow.
IMPORTANCE	Moderate. This practice is an effective way of minimizing the impacts associated with gathering firewood. These impacts are usually not particularly widespread, however.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Moderate. Campers in popular destination areas and in environments with low productivity may have to forgo campfires. In most cases, however, they retain the option of visiting places where campfires are less detrimental.

PRACTICE 39—DO NOT BUILD A FIRE WHERE FIRE DANGER IS HIGH

DESCRIPTION	Fire danger can be extremely high in certain places, at certain seasons, in particularly dry years, or when winds are high. Fires should not be built during these situations. If there is any question, visitors should check with managing agencies for fire danger or closures.
SAMPLE MESSAGE	"Avoid use of fires when fire hazard is high." (30)
PROBLEM ADDRESSED AND RATIONALE	General disturbance of natural conditions. Obviously, fires should not be built when there is a substantial risk that they could start a wildfire.
IMPORTANCE	High. A wildfire started by a careless camper is one of the more significant impacts of recreational use.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Low. There are relatively few places and times when this should constrain options.

PRACTICE 40—BUILD FIRES ON MINERAL SOIL WHERE TREES, ROOTS, VEGETATION, OR ROCKS WILL NOT BE SCARRED

DESCRIPTION	Select a fire site where it is possible to build the fire on mineral soil, rather than on duff, vegetation, or rock. Usually this involves finding an established fire site or a place where mineral soil is exposed or underneath a thin layer of duff that can be removed. It is also possible, with care, to build a fire on a mound of mineral soil placed on rock (see action 45). The fire should also be far enough from trees, roots, overhanging branches, and large rocks so they are not blackened or harmed. Avoid building a fire in dense vegetation.
SAMPLE MESSAGE	"Never build a fire in deep, woody forest duff, on peat, or on humus. Never build one next to a log or tree, next to a clean standing rock, or on vegetation. Instead, find mineral soil of some sort." (1)
PROBLEMS ADDRESSED AND RATIONALE	(1) Deterioration of established campsites and (2) proliferation of campsites. This action seeks to avoid long-term and unnecessary fire scars on rocks, trees, and vegetation. Scars on mineral soil, in contrast, can be scattered and/or covered. The action also seeks to avoid starting a wildfire through burning in duff. Any of these undesired scars can represent unnecessary impact on established campsites or leave long-term evidence of use on previously unused sites. Such evidence can encourage repeat use and the development of a new campsite.
IMPORTANCE	High. Creating a fire scar is perhaps the fastest way to cause long-term impact to a previously unused site. Therefore, building fires on mineral soil (along with careful fire construction and cleanup practices) is critical to avoiding campsite proliferation. It is also an effective means of avoiding unnecessary and unsightly impacts on established campsites.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Low. More time may be required to find or create an appropriate location for a fire.

PRACTICE 41—IN PLACES WITH WELL-IMPACTED CAMPSITES, BUILD FIRES IN EXISTING FIRERINGS OR ON FIRE SCARS

DESCRIPTION

When camping in an area that has well-impacted campsites and existing firerings, build campfires in an existing ring, or at least in a place that has already been scarred by fire. Do not build a campfire on a previously undisturbed spot. When selecting among several existing firerings, select one that will make it easy to concentrate onsite activities (practice 32).

SAMPLE MESSAGE

"[In heavily used areas] if fires are permitted, use an existing fire circle rather than build a new one." (8)

PROBLEMS ADDRESSED AND RATIONALE

(1) Deterioration of established campsites. This is an additional aspect of the policy of concentrating use and impact on places that are already well impacted, in this case on a single spot on each campsite where fires have already been built. If this is not done, fire impacts are likely to spread around the site, leaving an unappealing and more highly impacted campsite. (2) Proliferation of campsites. This problem can be avoided by concentrating use and impact on campsites where fires have already been built. Otherwise, campfire impacts will spread to new sites that will likely deteriorate over time.

IMPORTANCE

High. Campfires are among the most common, visually obtrusive, and long lasting of impacts. This practice is critical to limiting the proliferation of campfire scars in popular destination areas. It is also important to keep established firerings clean and attractive (practice 49).

CONTROVERSIAL ELEMENTS

Attempts to make universally applicable rules about either always building fires in existing firerings or building fires on previously unused sites have been contradictory. Use of existing firerings is most appropriate in frequently used areas, while previous fire sites should be rehabilitated and avoided (practice 42) in remote places. The concept is to concentrate use and impact in popular places and to disperse use and impact in little-used places. The controversy results from attempting to develop a single simple rule.

KNOWLEDGE NEEDS

None.

FREQUENCY OF RECOMMENDATION

Common.

COSTS TO VISITORS

Low. Existing firerings are the most convenient places to build fires anyway. If campers want to select their own fire site, they have the option of visiting appropriate low-use areas.

PRACTICE 42—IN PLACES WITHOUT WELL-IMPACTED CAMPSITES, DO NOT USE EXISTING FIRERINGS OR SCARS; DISMANTLE ANY RINGS

DESCRIPTION	When in an infrequently used area without well-developed campsites, dismantle and camouflage any firerings that you find. Do not use them and do not camp there. Select a site without obvious disturbance for camping and fire building.
SAMPLE MESSAGE	"If a fire ring shows signs of recovery, such as plant recolonization, you should disassemble the fire ring and camouflage the area so that future camping in the area will be discouraged." (3)
PROBLEM ADDRESSED AND RATIONALE	Proliferation of campsites. This practice complements practice 24 (in remote locations, select a previously unused campsite). A firering serves as evidence of previous impact. It should be avoided, and the fire evidence should be removed so that others will not be attracted to the site. Repetitive use of a lightly impacted site will cause deterioration (Cole 1987b).
IMPORTANCE	Moderate to high. This practice is particularly important where use levels are moderately high—almost to the level where it would be better to concentrate use on a few well-impacted campsites. It is always an important means of avoiding pronounced campfire impacts and the proliferation of campsites.
CONTROVERSIAL ELEMENTS	Some low-impact materials suggest that campfires should always be built in existing rings. This recommendation is appropriate in places with well-impacted sites (practice 41), but it results in unnecessarily impacted and obtrusive fire sites when applied in low-use places. The controversy results from attempting to develop a single universally applicable rule.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Moderate. This practice requires visitors in remote areas to take the extra time and care to build fires on a previously unused site. It is always easier to use an existing fire site. Visitors who want the ease of fire in an existing site have the option of visiting well-impacted places.

PRACTICE 43—GATHER FIREWOOD AWAY FROM CAMP; DISPERSE YOUR GATHERING

DESCRIPTION	Walk some distance from the immediate camp area to collect firewood. Gather a few pieces here and there, always leaving some wood on the ground. Do not take the last pieces of wood from any area.
SAMPLE MESSAGE	"Gather wood some distance from camp on existing sites and always leave some wood, so the area does not look denuded." (30)
PROBLEM ADDRESSED AND RATIONALE	Deterioration of established campsites. Dispersal of gathering and a willingness to search some distance from camp can avoid the common situation of an area totally devoid of down wood around frequently used campsites.
IMPORTANCE	Low to moderate. The ecological impact of concentrated firewood gathering may not be severe (Cole and Dalle-Molle 1982), as long as large woody debris is not collected (practice 44). But the esthetic effect is pronounced and can easily be avoided.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Low. A little more time may be required to collect firewood. By not bothering to search in the picked-over area close to campsites, time is saved, however.

PRACTICE 44—USE ONLY DEAD AND DOWN FIREWOOD THAT YOU CAN BREAK BY HAND

DESCRIPTION	Select firewood from pieces that are dead and lying on the ground. Pieces should be small enough to break in your hands and fit within the fire site. Do not collect wood from standing trees, dead or alive, and do not collect or chop up large pieces of wood. There is no need for an ax or saw.
SAMPLE MESSAGE	"Remember when you gather wood that it must be both dead and down to be eligible. Rooted, rotten snags are not firewood: they are habitat and hunting territory for owls, woodpeckers, and a whole community of animals small and large. Don't use wood you can't break. Axe and hatchet are no part of the wilderness tool kit today." (1)
PROBLEMS ADDRESSED AND RATIONALE	(1) Deterioration of established campsites and (2) general disturbance of natural conditions. Collection of wood that is not dead and down represents unnecessary disturbance of vegetation, which may be important for a variety of animals, particularly cavity-nesting birds. Collection of large pieces of down woody debris causes problems that do not result from the removal of small pieces of wood. Large woody debris plays an important and irreplaceable role in the ecosystem—in water and nutrient conservation, as a substrate for biological activity, and in other ways (Cole and Dalle-Molle 1982). The tree components which in the long term are most important to nutrient cycling are the leaves or needles and twigs (Weetman and Webber 1972), so removal of small pieces of wood causes little problem. Hacking of large downed wood and standing wood also causes pronounced esthetic impacts.
IMPORTANCE	Moderate. This practice would be effective in minimizing the impacts associated with the collection of firewood. These impacts are highly localized and probably not among the most critical.
CONTROVERSIAL ELEMENTS	Stock parties in particular tend to bring axes and saws to cut firewood. In fact, an ax is useful for stock parties to chop out trail obstacles. There may be some resistance to the idea of not chopping firewood, despite the fundamental ecological rationale for the recommendation.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Use only dead and down firewood is a very common recommendation. The recommendation to use small pieces that can be broken by hand is uncommon.
COSTS TO VISITORS	Low. Firewood collection should take no longer. Extra time spent in collection will be offset by time saved in chopping wood.

PRACTICE 45—ON PREVIOUSLY UNUSED FIRE SITES, BUILD FIRE IN A SHALLOW PIT OR ON A MOUND OF MINERAL SOIL

DESCRIPTION

Fires should be built either in a shallow pit in mineral soil or on a mound of mineral soil. Mound fires are an appropriate way to have a fire on rock. In neither case should a fire be built where vegetation is dense. For a mound fire, locate a source of sand or mineral soil that will not be disturbed by excavation and redeposition of material. Build the fire on top of a 6-inch-deep layer of mineral soil. For a pit fire, clear any duff or sparse vegetation; dig a shallow pit; and build the fire in this pit. See the example below and Hampton and Cole (1988) for more detail.

SAMPLE MESSAGES

"When looking for a potential fire site in a pristine area, . . . choose a surface of mineral soil, thin duff (less than 2-3 inches thick), sparse vegetation, or a flat rock. Never build a fire in thick duff because the danger of fire spreading is great. Avoid fires in dense vegetation because it is difficult to not damage the vegetation."

"Fires can be built either on a mound or in a pit. Mound fires are preferable if an adequate supply of sand or mineral soil can be found without damaging the source area."

"**Mound fire**: Spread a layer of soil about 6 inches deep on top of the ground surface, over an area larger than the fire will occupy. Build the fire on the soil. Mound fires are most likely to be built on mineral soil, duff, or rock. . . . [When cleaning up], scatter the soil and ash and camouflage the surface with mineral soil or litter and duff (whatever matches the surroundings). If the mound was built on a rock, rinse the rock off."

"**Pit fire**: In mineral soil, simply dig a shallow pit several inches deep. Build the fire in the pit. Where there is a thin duff layer or sparse vegetation, clear the duff down to mineral soil from a circle several feet in diameter; build the fire in a shallow pit in the center of the circle of mineral soil . . . . [To clean up, scatter ash], fill [the pit] in, and camouflage the site." (30)

PROBLEM ADDRESSED AND RATIONALE

Proliferation of campsites. Campfire remnants and scars are one of the most obvious signs of human use in remote areas and on little-used sites. They provide unnecessary evidence of human presence and, by encouraging repeat use, contribute to the creation of new campsites. Proper campfire construction, along with careful cleanup on previously unused sites, can minimize these problems.

IMPORTANCE

High. Proliferation of fire scars and campsites in little-used places is one of the more serious unnecessary problems in wilderness. This practice, along with proper campfire cleanup and appropriate campsite selection and behavior, is critical to avoiding this problem. If these practices are followed, campsite impact can be virtually absent from the vast majority of the acreage of most wilderness and backcountry areas.

CONTROVERSIAL ELEMENTS

These specific practices are not controversial. Many educational brochures also describe a technique for building fire in a hole cut in dense vegetation. This technique has a high potential for causing damage and has been abandoned, due to poor success, by the National Outdoor Leadership School (NOLS) (which was largely responsible for developing the original technique). It is covered in the section on practices that can be counterproductive (refer to page 98). Its effectiveness has never been rigorously evaluated. Some areas have regulations that prohibit building fires outside of designated areas or in places where fires have never been built before.

KNOWLEDGE NEEDS

The effectiveness of these construction methods (and the more controversial method for dense vegetation) has never been rigorously evaluated. Evaluative research could improve our ability to precisely state construction specifications and preferred methods.

FREQUENCY OF RECOMMENDATION

Uncommon.

COSTS TO VISITORS

Low to moderate. Proper construction of campfires on previously unused sites requires care and some time and effort. This is one of the costs of using remote sites.

PRACTICE 46—DO NOT RING A FIRE WITH ROCKS

DESCRIPTION	(This practice applies primarily to previously unused sites). Do not build a ring of rocks around the fire. Rocks do not increase fire safety. For cooking, use a stove, a grill with folding legs, or, as a last resort, two rocks to support a grill.
SAMPLE MESSAGE	"Resist the temptation to build a rock fire circle. You may want to use a small rock or two to support cooking pots, but a full circle is not needed and does not prevent fire from spreading." (8)
PROBLEM ADDRESSED AND RATIONALE	Proliferation of campsites. Blackened rocks are one of the obvious scars left by campfires. Minimizing or avoiding use of rocks limits this problem.
IMPORTANCE	Low to moderate. Provided that other low-impact practices are followed in little-used places, this practice is not critical. It is, however, an effective and easy way to avoid unnecessary impact. This practice is most important where multiple firerings are built on well-impacted sites and where fires are built on undisturbed sites close to well-impacted campsites; however, both of these situations should not exist if practices 23 (in popular locations, select a well-impacted campsite) and 41 (in places with well-impacted campsites, build fires in existing firerings or on fire scars) are followed and campers and managers leave a single clean firering on well-impacted sites (practice 49). Because these other practices are not always followed, and this one entails few costs, it should be encouraged.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Low. No change in practices is required.

PRACTICE 47—KEEP FIRES SMALL

DESCRIPTION	Campfires should be small. The area of the fire, size, and amount of firewood should all be minimized.
SAMPLE MESSAGE	"Build small fires—not large warming fires." (7)
PROBLEM ADDRESSED AND RATIONALE	(1) Deterioration of established campsites, (2) proliferation of campsites, and (3) general disturbance of natural conditions. The basic rationale is to minimize the consumption of firewood and the area impacted by campfires.
IMPORTANCE	Low to moderate. This practice increases in importance as demand for firewood increases and supplies of firewood decrease.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Common.
COSTS TO VISITORS	Low. Small campfires are generally at least as functional as large ones. Desires for large bonfires must be suppressed, particularly in popular places and places where firewood is scarce.

PRACTICE 48—BURN CHARCOAL TO ASH; SOAK ASHES; SCATTER EXCESS FIREWOOD

DESCRIPTION	Toward the end of the fire, stop adding large pieces of wood and concentrate on burning charcoal down to ash. When charcoal has burned to ash, soak the ashes to make certain the fire is out. Ashes should be cool enough to touch with your bare hand. Scatter any excess firewood away from the camp. Then, if you were using an existing fire site, leave the firering clean (practice 49); if you were using a previously unused site, remove all evidence of the fire (practice 50).
SAMPLE MESSAGES	"Stop adding fuel well before you wish to put the fire out. Keep pushing all half-burnt wood into the center of the fire until only white ash remains. Thoroughly soak the entire firepit with water." (9) "You should not have collected more wood than you needed, but if you have, scatter it also. Diffusion is a major strategy of minimum-impact camping; extra wood should be spread lightly so it will not be noticed." (3)
PROBLEMS ADDRESSED AND RATIONALE	(1) Deterioration of existing campsites. Proper cleanup leaves existing campsites more attractive for the next party. (2) Proliferation of campsites. This practice is most important in avoiding site proliferation. Leaving a fire site clean on an established campsite encourages subsequent use; the next party is less likely to camp elsewhere and disturb another site. On previously unused sites, this practice is one of the first steps in removing evidence of use, thereby avoiding encouragement of further use and eventually the development of new campsites.
IMPORTANCE	Low to moderate, except that soaking is always important as a means of avoiding wildfire. This practice is less important on established campsites.
CONTROVERSIAL ELEMENTS	In some places it is a time-honored tradition to leave a pile of firewood for the next camper. On established sites this may be acceptable, although it is unnecessary and does run counter to the philosophy of leaving little evidence of your stay.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Low. Some time is required to let the fire burn down, but this is not a burden and no major behavioral changes are required.

PRACTICE 49—ON PREEXISTING FIRE SITES, LEAVE THE FIRERING CLEAN AND ATTRACTIVE; DISMANTLE EXTRA FIRERINGS

DESCRIPTION

When camping on a well-impacted campsite, campfires should be built where fires have been built before. A small, clean fire site should be left. If there was originally a ring of rocks, leave a ring of rocks. If the ring was overly large and built up, excess rocks should be scattered, away from the campsite. If it was clogged with charcoal and ash, this material should also be scattered away from the site. Scatter rocks, charcoal, and ash lightly in a number of places—to be as inconspicuous as possible. Other firerings on the site should be dismantled completely. Scatter rocks, charcoal, and ash away from the site and attempt to camouflage the fire scar. Any litter should be carried out.

SAMPLE MESSAGES

"If using a pre-existing fire site, leave a small clean firering to attract the next user. If large quantities of ash were generated by you or previous users, scatter it some distance from the campsite. Any excess blackened rocks—from an over-built firering or from multiple firerings—should be returned to their original locations, if possible, or scattered some distance from the camp." (30)

"Fire rings have a habit of proliferating around camps. Destroy extra ones by spreading out the rocks, scattering the ashes and covering with soil or duff." (40)

PROBLEMS ADDRESSED AND RATIONALE

(1) Deterioration of existing campsites and (2) litter. Overbuilt, sloppy firerings, extra rings, scattered fire debris, and litter represent significant esthetic impacts. This action seeks to avoid this unnecessary problem. Leaving a single clean ring will tend to confine the impacts associated with campfires by encouraging others to build campfires in that same place. (3) Proliferation of campsites. An attractive site, by encouraging repeat use, also helps avoid the creation of new campsites by users who would choose not to use a campsite littered with firerings, blackened rocks, charcoal, and ash.

IMPORTANCE

High. This is one of the more important practices on well-impacted campsites. Widespread campfire debris and litter are unnecessary impacts that are particularly obtrusive and displeasing to subsequent campers. This practice can eliminate those problems and make camping in frequently used, well-impacted destination areas more pleasant.

CONTROVERSIAL ELEMENTS

Some low-impact materials suggest that all firerings on campsites should be dismantled, regardless of circumstances. On frequently used sites, this frequently results in fire impacts spreading around a site as new firerings are built in different places. As a universal suggestion, dismantling all firerings is not recommended; it is appropriate in remote, little-used places (practice 50).

KNOWLEDGE NEEDS

None.

FREQUENCY OF RECOMMENDATION

Uncommon.

COSTS TO VISITORS

Low. It does take some time to carefully clean out firerings and debris. Time spent will diminish, however, as others learn to behave properly. This time is merely the cost associated with being able to have a campfire.

PRACTICE 50—ON PREVIOUSLY UNUSED FIRE SITES, REMOVE ALL EVIDENCE OF THE FIRE

DESCRIPTION	After having a campfire in a place where fires have not been built before, remove all evidence of the fire. Either a pit or mound fire should have been built. With a pit, simply fill in the pit with excavated mineral soil and camouflage the disturbance with soil or duff—whatever will blend in with the surroundings. With a mound fire, return the ash and soil to its source or scatter it widely. If built on a rock, rinse the rock. Again, camouflage the site. All wood and charcoal should have been burned to ash; if it was not all burned, remove it from the ashes and scatter it widely. Rocks should not have been blackened, but if they were, scatter them widely. Refer to Hampton and Cole (1988) for more detail.
SAMPLE MESSAGE	"If you have been using a firepit, drown the ashes and coals, scatter all remaining ashes, and return most of the mineral soil you removed back to the hole. Now look at the surrounding ground cover, and camouflage the top of the firepit to match. Use duff, aspen leaves, pine cones, whatever it takes to restore the surface to its natural state. Always be careful not to overcamouflage. A big pile of duff is a sure giveaway that there is something underneath. Good camouflaging is an art that takes a subtle touch. If you have built a flat rock (mound) fire, scatter the ashes and return the mineral soil to where you got it. Rinse the rock with water, wash off any remaining residue of soil, and landscape the entire area." (3)
PROBLEM ADDRESSED AND RATIONALE	Proliferation of campsites. Evidence of a campfire can encourage subsequent users to camp at the same spot. Where this happens, campsites develop rapidly. Removing evidence of campfires, along with proper campsite selection and behavior, eliminates this threat.
IMPORTANCE	High. Effective elimination of campfire evidence in remote places is critical to maintaining such places in a virtually undisturbed condition. It is one of the responsibilities that must be accepted when building a campfire in remote places.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Low to moderate. This practice requires a commitment of time to mitigate the disturbance caused by campfires. Proper fire site selection and construction can minimize time requirements, however. For those who do not want to take the time, options include not having a campfire and visiting places with well-impacted campsites and established fire sites.

Waste Disposal and Sanitation

PRACTICE 51—PACK OUT NONORGANIC LITTER (OR BURN READILY BURNED LITTER)

DESCRIPTION

All nonorganic litter should be burned or packed out; it should not be buried or scattered. Paper products, including toilet paper, can usually be burned. Where fires are not permitted, paper products should be packed out, as should cans, bottles, plastic products, and anything else that cannot be completely burned. Special care must be taken to avoid leaving inconspicuous pieces of litter (such as "twist-ties") or the aluminum foil that lines paper products and will not burn.

SAMPLE MESSAGES

"You will want to pack out every bit of garbage that cannot be completely burned. Don't bury it." (7)

"The basic rule of waste disposal is to pack out what cannot be otherwise disposed of by careful meal planning. Only waste water and fish viscera should be scattered and burning of waste should be minimized." (30)

"Minimize the use of toilet paper. If it is used, either pack it out (ideally) or burn it as completely as possible and bury any remnants. Do not burn toilet paper if fire hazard is high or regulations prohibit it. Tampons should be packed out (unless you are in grizzly bear country) or burned in a very hot fire; they should never be buried." (30)

PROBLEM ADDRESSED AND RATIONALE

Litter. Removing all nonorganic waste products that are brought into the wilderness will eliminate litter problems.

IMPORTANCE

High. Litter is not a long-term ecological impact problem; however, it is one of the more serious problems in the opinion of wilderness users (Roggenbuck and others 1982; Stankey 1973). This practice, if faithfully applied by all users, would eliminate litter problems.

CONTROVERSIAL ELEMENTS

The concept of packing out what you pack in is generally accepted. The handling of toilet paper is controversial, however. Many land managers dislike the idea of burning it because this increases the risk of wildfire; users dislike the idea of packing it out. Burying toilet paper is the less-than-desirable compromise that is often suggested.

KNOWLEDGE NEEDS

None.

FREQUENCY OF RECOMMENDATION

Very common.

COSTS TO VISITORS

Low. All this practice requires is that visitors pack out what they pack in, minus what they eat and can burn. Only packing out toilet paper can be undesirable.

SPECIAL SITUATIONS

In grizzly bear country, odorous materials can attract bears. Do not pack out containers that hold odorous material. Through careful pretrip planning, odorous foods should be kept to a minimum and containers that are not burnable should be avoided.

PRACTICE 52—PICK UP OTHER PEOPLE'S LITTER

DESCRIPTION	In addition to packing out your own litter, pick up as much of that left by others as possible
SAMPLE MESSAGE	"Pick up trash left by others and carry the "leave no trace" ethic the extra mile—a true "goc turn" for all who enjoy wilderness and the backcountry." (8)
PROBLEM ADDRESSED AND RATIONALE	Litter. This practice will remove some of the litter problem created by unconscientious use
IMPORTANCE	Low to moderate. This practice can help reduce litter problems, but deals with symptoms rather than the cause. It is less important than practice 51 (packing out your own litter).
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Common.
COSTS TO VISITORS	Low. Even relatively little effort and weight addition can be helpful.

PRACTICE 53—PACK OUT OR BURN ORGANIC GARBAGE (OR SCATTER FISH VISCERA)

DESCRIPTION	Small quantities of organic garbage (food scraps) can be burned in a hot fire. Large quantities are difficult to burn and should be packed out. Do not scatter or bury food scraps; they will attract animals. Fish viscera can be widely scattered, but should not be thrown back in lakes or streams. Packing them out or burning them is better, however.
SAMPLE MESSAGES	"Select low-waste foods and prepare them in quantities that will be eaten completely. If you do have leftover debris, however, pack it out with your other garbage." (23) "Litter and food scraps can be minimized with careful planning and preparation. Food can be carefully measured so leftovers are minimized. When food is left, it should be packaged up and either eaten later or packed out. Partial burning, which is likely to occur when food is burned at the end of a meal, is unacceptable. Fish viscera are generally a natural part of the ecosystem. They should be scattered widely, out of sight and away from campsites. In high-use areas and in bear country they should be scattered a long way from camps. Do not throw viscera back into lakes and streams (unless bear danger is high and viscera can be thrown into deep water); the cool temperatures in most mountain waters prevent rapid decomposition." (30)
PROBLEMS ADDRESSED AND RATIONALE	(1) Litter and (2) disturbance of feeding habits. Both of these problems can be avoided if waste is packed out or completely burned. Widespread scattering may make litter problems unobtrusive; however, it can alter the feeding habits of animals.
IMPORTANCE	Moderate. Organic wastes decompose more rapidly than nonorganic litter and are probably less of a problem in the opinion of wilderness users. This practice is an effective means of minimizing problems, however.
CONTROVERSIAL ELEMENTS	The pack-it-out, burning, and scattering options for disposal can all be found in the literature. Clearly, packing it out is the option most consistent with minimum-impact use; however, the other options are more convenient for users. The recommendations described above represent compromises between convenience and "doing the right thing."
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Low. In all cases, less must be packed out than was packed in.
SPECIAL SITUATIONS	In grizzly bear country, food scraps should not be packed out. Special care in planning is required. Leftovers that cannot be burned should be scattered a long way from camp.

PRACTICE 54—USE TOILETS IF PROVIDED

DESCRIPTION	When camped in an area where toilets are provided, use them. Do not practice the dispersed cathole method (practice 55).
SAMPLE MESSAGE	None found, although the practice is implied in most areas where toilets are provided.
PROBLEM ADDRESSED AND RATIONALE	Human waste. Toilets concentrate human waste in a single place. This should reduce the risk of accidental contamination.
IMPORTANCE	Moderate to high. In places where toilets are constructed, use levels are usually very high. In such places, use of toilets—assuming they are properly located and maintained—effectively minimizes the risk of contamination. The severity of the health risk associated with dispersed catholes is unclear, however. We do know that pathogens are capable of surviving in buried feces for years (Temple and others 1982).
CONTROVERSIAL ELEMENTS	The appropriateness of toilets in wilderness is questioned. Decisions about appropriateness involve tradeoffs between human health and esthetics and the provision of structures.
KNOWLEDGE NEEDS	A better understanding of fecal decomposition rates and the risks of contamination would provide a better basis for evaluating the importance of this practice and the situations in which provision of toilets are or are not needed.
FREQUENCY OF RECOMMENDATION	None.
COSTS TO VISITORS	Low. Many visitors dislike the use of toilets; others prefer using toilets (Stankey and Schreyer 1987). Those who dislike toilets can visit less popular places where toilets are not needed. Providing information on the location of toilets in the backcountry is important.

PRACTICE 55—DISPOSE OF HUMAN WASTE IN A PROPERLY LOCATED CATHOLE

DESCRIPTION

In an area without toilets, human waste should be disposed of in a place where it will not pollute waters and where other people will not find it. Catholes should be widely dispersed, as far from campsites, trails, lakes, and streams as possible. Waste should be buried in a small hole excavated in mineral soil, a place where disturbance will be minimal. Do not simply cover feces with a stone. A small trowel can be helpful. Do not build a latrine (refer to page 99).

SAMPLE MESSAGE

"For individuals, dig small latrines (cat-holes) in the top 6 to 8 inches of soil at least 200 feet from water, camp, and trails. Cover your latrine thoroughly with soil, rocks, needles, and twigs." (8)

PROBLEMS ADDRESSED AND RATIONALE

(1) Human waste and (2) water pollution. Where toilets are not provided, individuals must be responsible for depositing waste in a manner and place that minimize the risk that others will encounter the waste or that it will reach water supplies. These risks can be most effectively minimized by walking far from campsites, trails, and water bodies to seek a disposal site. Adequate burial adds further protection from risk of pollution or encountering waste. Contrary to popular belief, burial is not a means of increasing decomposition; it is primarily a means of slowing dispersal toward water and separating waste from other humans. The importance of widespread dispersal of waste disposal sites is suggested by recent research that reported survival of pathogenic indicators for a year or more (Temple and others 1982).

IMPORTANCE

Moderate to high. Importance varies with amount of use. This practice is of critical importance in regularly visited places. In remote, little-visited places, however, disposal practices can be more lax. In unused places, surface disposal is acceptable; this will increase decomposition rates and avoid the disturbance associated with excavating a hole. (Surface disposal should probably not be generally recommended.) Given the significance attached to problems of esthetics and human health, this practice is among the most important in regularly visited places. It becomes both increasingly important and increasingly difficult as use intensities increase.

CONTROVERSIAL ELEMENTS

Attempts to establish quantitative standards have resulted in inconsistent recommendations. Recommended appropriate distances from campsites, trails, and water range from 100 to 300 feet. Recommended depths for disposal range from 4 to 10 inches. These differences are not critical, although it would be best—for distance from campsites—to suggest that visitors go as far as possible. Other recommendations include use of group latrines and deposition on the surface. These practices are not generally recommended, although there are special situations where they might be appropriate.

KNOWLEDGE NEEDS

Rapid decomposition of waste reduces risk of contamination. We need to know more about environmental factors that promote rapid decomposition of feces. This would improve our ability to provide more specific recommendations about good disposal sites.

FREQUENCY OF RECOMMENDATION

Very common.

COSTS TO VISITORS

Moderate. This practice requires some time and care to walk far enough from camp and to excavate an adequate hole.

SPECIAL SITUATIONS

Certain environments offer unique opportunities for human waste disposal. Crevasses on glaciers can make good disposal sites. Otherwise, proper waste disposal on snow and ice is difficult. Selecting a site far from places that are used during any season becomes critical. Waste disposal below high tide offers an opportunity on low-use beaches. On rivers, equipment is available that permits all waste to be carried out in portable toilets (Hampton and Cole 1988). This is an extremely effective means of minimizing problems. Waste deposition on the surface may be appropriate in very lightly used areas where excavation of holes can cause long-term impact. Spreading the feces on a dry and exposed site will maximize exposure to sunlight and, therefore, decomposition. Finally, latrines may be necessary for long stays by large groups in popular areas. This situation should be avoided, however, because decomposition rates are extremely slow in latrines, and excavation by animals is a serious problem.

PRACTICE 56—USE BIODEGRADABLE SOAP IN SMALL AMOUNTS, IF AT ALL

DESCRIPTION	Minimize use of soap. Use small quantities of a biodegradable soap and keep soap out of water bodies (practice 57).
SAMPLE MESSAGES	"Minimize your use of soaps since even biodegradable soaps are pollutants." (86) "The use of soaps or detergents containing phosphates must be avoided to prevent contamination of backcountry water sources and vegetation damage." (9)
PROBLEMS ADDRESSED AND RATIONALE	(1) Water pollution. Pollution of water is avoided by keeping all soap, even biodegradable soap, out of water bodies. (2) General disturbance of natural conditions. Disturbance, most often on and around campsites, is minimized by using biodegradable soap in small quantities. Soap with phosphates adds nutrients to soils, which can lead to alteration of vegetation.
IMPORTANCE	Low to moderate. The significance of problems created by soap pollutants is poorly understood. As long as soaps are kept out of water bodies (practice 57), problems may not be substantial.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	Although it would not change the recommendation, a better understanding of the nature and significance of soap pollution would permit an evaluation of importance.
FREQUENCY OF RECOMMENDATION	Common.
COSTS TO VISITORS	Minimal.

PRACTICE 57—BATHE, WASH, AND DISPOSE OF WASTE WATER AWAY FROM WATER BODIES AND CAMPSITES

DESCRIPTION	Bathing in water bodies is acceptable if soap is not used. If soap is used, get wet; carry water in a pot to a place away from the water and campsites; soap and lather up; and rinse off. Dishes should also be washed away from water bodies and campsites so that soap, food scraps, and waste water do not pollute them.
SAMPLE MESSAGE	"All soap pollutes lakes and streams. If you bathe with soap, jump into the water first, then lather at least 100 feet from the water, and rinse the soap off with water carried in jugs or pots. This allows the biodegradable soap to break down and filter through soil before reaching any body of water. Clothes can be adequately cleaned by thoroughly rinsing. Soap is not necessary. Dishes should be washed away from water sources. Dishwashing is simple; don't use soap. If food sticks, fill the pan with cold water and let it soak several hours or overnight (except in grizzly bear country). Clean jars or narrow-mouthed containers by shaking pebbles and water inside them. Scrub the insides of pots with sand, gravel, pine cones, or a pine needle cluster." (6)
PROBLEMS ADDRESSED AND RATIONALE	(1) Water pollution. Soap and food scraps can pollute water bodies by contributing nutrients that had limited aquatic growth. Water clarity can be adversely affected and the food chain can be altered. (2) Deterioration of established campsites. In camp, food scraps can draw flies and be esthetically unattractive.
IMPORTANCE	Unknown, probably moderate. The susceptibility of water bodies to pollution and the significance of potential problems is poorly understood. Lakes in a heavily used lake basin in the Sierra Nevada have unusual chemistry and biota believed to reflect a history of heavy use and water pollution (Taylor and Erman 1979, 1980). Problems may be confined to water bodies with high susceptibility in places that are heavily used. This practice can alleviate problems even under these circumstances.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	Although it would not change the recommendation, a better understanding of the nature and significance of water pollution would permit a better evaluation of importance.
FREQUENCY OF RECOMMENDATION	Very common.
COSTS TO VISITORS	Moderate. This practice requires more time and energy than washing and bathing directly in water.
SPECIAL SITUATIONS	In grizzly bear country it is important to wash dishes immediately after use, in an area far from sleeping places. Where risk is very high, washing directly in water may be justified as a means of minimizing odors.

Additional Practices for Parties With Stock

PRACTICE 58—USE PROPERLY TRAINED STOCK

DESCRIPTION

Stock should be in good condition for mountain travel. Stock should be trained to methods of containment that will be used, as well as equipment. Stock should be fed weed-free food for several days before entry.

SAMPLE MESSAGE

"Animals conditioned to strenuous mountain travel are at home on the trail and accustomed to supplemental feeds and various methods of containment. Horses that react to strange looking ropes or corrals can cause damage or injure themselves. Introducing stock to hobbles, picket pins, hitch lines, and various temporary corrals in a familiar environment may avert a major calamity at some remote camp." (19)

PROBLEMS ADDRESSED AND RATIONALE

(1) Deterioration of established trails, (2) deterioration of established campsites, (3) proliferation of campsites, and (4) deterioration of grazing areas. Properly trained stock can be managed more easily; therefore, it is more likely that such stock will be handled properly. Properly trained stock are more likely to stay on trails and to cause less damage around campsites and in grazing areas. They are less likely to need to be confined, a practice that commonly results in severe alteration.

IMPORTANCE

Moderate. This practice makes it easier to apply other low-impact stock practices.

CONTROVERSIAL ELEMENTS

None.

KNOWLEDGE NEEDS

None.

FREQUENCY OF RECOMMENDATION

Rare.

COSTS TO VISITORS

Low to moderate. Although this practice requires advanced planning and preparation, it will contribute greatly to a more enjoyable trip.

PRACTICE 59—CARRY APPROPRIATE EQUIPMENT

DESCRIPTION	Horses should be shod with flat plates or not at all. Other items to bring include supplemental feed, nosebags (for feed), hobbles, a hitch line with "tree-saver straps" (USDA FS 1981), and bug repellent and fringed eye guards to reduce aggravation caused by flies and mosquitoes. Carry an ax to chop out downed logs, but avoid using it to gather firewood (practice 44). Follow the recommendations on equipment for all wilderness users (practice 2). Otherwise, take as little equipment and as lightweight equipment as possible to minimize the number of stock.
SAMPLE MESSAGE	"Take only as much gear as you need for the trip. Use lightweight gear. Use picket lines or hobbles. Pack in processed grains and hay pellets where grass is scarce." (12)
PROBLEMS ADDRESSED AND RATIONALE	(1) Deterioration of established trails, (2) development of unwanted trails, (3) deterioration of established campsites, (4) proliferation of campsites, and (5) deterioration of grazing areas. Proper and lightweight equipment will minimize the inevitable "wear-and-tear" caused by packstock. Use of supplemental feed will reduce grazing impacts. Equipment designed to minimize the impact caused by confined stock is particularly important.
IMPORTANCE	Moderate to high. In places with substantial packstock use, stock impacts are severe except where special care is taken to limit those impacts. These suggestions make it easier to be gentle to the land.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Moderate to high. Many stock users have become accustomed to a style of wilderness use that includes large quantities of heavy equipment. This tradition needs to change and be replaced by use of lightweight equipment more similar to that used by the backpacker.

PRACTICE 60—MINIMIZE THE NUMBER OF STOCK

DESCRIPTION	Take as few head of stock as possible. Minimizing the amount and weight of equipment is critical to minimizing the number of stock.
SAMPLE MESSAGES	"Take the minimum number of stock to make your trip successful." (9)
PROBLEMS ADDRESSED AND RATIONALE	(1) Deterioration of established trails and (2) deterioration of established campsites. Reducing the number of stock can reduce damage to existing trails and campsites in some places. (3) Development of unwanted trails and (4) proliferation of campsites. Of more importance, large parties are more likely to create new trails and campsites if they travel off trail or use previously undisturbed campsites. (5) Deterioration of grazing areas and (6) competition with wildlife. Grazing areas will deteriorate more rapidly and severely when large numbers of stock graze. In places, this can result in competition with wildlife. (7) Visitor conflict. Visitor conflicts between stock and backpacker parties are also more serious where stock parties are large.
IMPORTANCE	High. The size of stock parties influences the severity of a number of problems. Particularly in little-used and off-trail places, it is critical that stock party size is minimized.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Moderate to high. This can require a substantial change in style of use. Many traditional comfort and convenience items would have to be left behind. Most of these can be replaced by lightweight equipment used by backpackers.

PRACTICE 61—STOCK SHOULD STAY ON ESTABLISHED TRAILS AS MUCH AS POSSIBLE

DESCRIPTION

Parties with stock should travel as much as possible on designated trails, rather than taking off-trail routes. When on trails, stock should be tied together (practice 63) and led single file along the main tread. They should not be allowed to spread out or to walk on parallel or developing trails.

SAMPLE MESSAGE

"Stay on designated trails." (33)

"Keep your stock on the trail tread." (12)

PROBLEMS ADDRESSED AND RATIONALE

(1) Deterioration of constructed trails and (2) development of undesired user-created trails. Trampling impacts of packstock are particularly severe because considerable weight is carried on a small bearing surface (Weaver and others 1979). Therefore, vegetation and soil damage occur rapidly where stock leave the trail. This is why it is best for stock to stay on constructed trails as much as possible. Where stock leave the main trail tread, trail widening and development of parallel trails are likely. Where stock travel off trail, new trails can be created rapidly.

IMPORTANCE

Moderate. This practice can be effective in minimizing trail deterioration problems caused by packstock use; however, severe trail problems are usually more a result of poor trail location and design than of type of use.

CONTROVERSIAL ELEMENTS

None.

KNOWLEDGE NEEDS

None.

FREQUENCY OF RECOMMENDATION

Rare.

COSTS TO VISITORS

Moderate. Costs are minimal to most users—those who prefer trail travel. Those who enjoy off-trail travel will bear more cost, however. Off-trail travel with stock is acceptable if special care is taken (practice 6).

SPECIAL SITUATIONS

With careful planning, off-trail travel with stock is acceptable. The number of stock must be small, and parties should be prepared to practice low-impact techniques. Routes should be carefully selected for their durability.

PRACTICE 62—REMOVE TRAIL OBSTACLES INSTEAD OF SKIRTING THEM

DESCRIPTION	When encountering a trail obstacle, such as a fallen log, stock parties should remove it and make the main trail passable again. Do not leave the trail to skirt the obstacle. Notify the managing agency if the obstacle cannot be removed.
SAMPLE MESSAGE	"Trail obstacles are part of any wilderness journey. When possible riders clear trails to make travel easier for themselves and others. When a detour is necessary, local managers are notified so the trail can be cleared before an alternate route forms." (19)
PROBLEM ADDRESSED AND RATIONALE	Deterioration of constructed trails. Where stock leave the trail to skirt an obstacle, the trail will widen or an alternate tread will develop. This deterioration can only be avoided by removing the obstacle and keeping stock on the main tread.
IMPORTANCE	Moderate. This is an effective way to eliminate one cause of trail deterioration. It is not one of the more critical trail problems, however.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Moderate. Clearing obstacles requires time and effort on the part of stock parties, although in few situations will obstacles be frequent enough to require a prohibitive effort.

PRACTICE 63—LEAD STOCK ON THE TRAIL, RATHER THAN LOOSE-HERD THEM

DESCRIPTION	Stock should be tied together and led down the trail. They should not be turned loose and herded down the trail.
SAMPLE MESSAGE	"On the trail pack stock should be led rather [than] loose-herded." (9)
PROBLEMS ADDRESSED AND RATIONALE	(1) Deterioration of constructed trails. Loose stock will leave the constructed trail, widening it, creating parallel trails, and shortcutting switchbacks. Leading them on short strings will minimize these problems, as well as the risk of losing a load. (2) Visitor conflict. Leading stock will also cause less conflict with parties met on the trail.
IMPORTANCE	Low to moderate. Stock leaving the trail tread are a major cause of trail deterioration. This practice will reduce this source of trail problems.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Low. Leading stock is easier than herding them.

PRACTICE 64—TIE STOCK OFF TRAIL, ON A DURABLE SITE, WHEN TAKING A BREAK

DESCRIPTION	When it is time to take a break, move off the trail far enough so that other parties can pass unnoticed. Select a durable site for the break, tying stock in a place and manner that will not cause impact. Avoid tying stock to trees (practice 74).
SAMPLE MESSAGE	"At rest stops—even short ones—stock are tied well off the trail. It's courteous and minimizes trail wear. If it's a scenic overlook, historic site, or other popular stop, stock are kept out of the area." (19)
PROBLEMS ADDRESSED AND RATIONALE	(1) Deterioration of constructed trails. Taking a rest stop adjacent to the trail is likely to cause trail widening and deterioration at that spot. This can be avoided by moving off trail to a durable spot. (2) Too many encounters and (3) visitor conflict. Moving off trail will also reduce the number of trail encounters and conflicts between stock and hiker parties.
IMPORTANCE	Low to moderate. Although this practice reduces problems, contrary behavior is not one of the more serious sources of problems.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Low. This practice requires more time and care, but experiences are enhanced by getting away from the trail for breaks.

PRACTICE 65—AVOID PLACES THAT HAVE ALREADY BEEN HEAVILY GRAZED

DESCRIPTION

Places that have already been heavily grazed should not be grazed further. They can be used as camping areas if enough processed feed is available to avoid grazing. Otherwise, move to a camping area that has adequate forage.

SAMPLE MESSAGE

No straightforward statement of this recommendation was found. The following contains some of the idea:

"Be certain meadows in the area will support the grazing needs of the livestock. Both water and grass supplies should be carefully examined. Frequently used areas are often exposed to heavy grazing through the season. Overgrazing contributes to a reduction in the active strength of the grasses, adds to the trodden-out appearance of the meadows, provides opportunities for unwanted weeds to grow and generally adds to the degradation of the area. The amount of feed available or the amount of feed packed in will determine the length of your stay." (9)

In some areas, overgrazed meadows have been closed to grazing.

PROBLEM ADDRESSED AND RATIONALE

Deterioration of grazing areas. Further grazing of meadows that have already been heavily grazed is likely to cause long-term deterioration. This practice should avoid that.

IMPORTANCE

High. This practice is critical to avoiding the degradation of grazing areas.

CONTROVERSIAL ELEMENTS

The concept is not controversial; however, there is probably little agreement on how much grazing meadows can sustain before further grazing should be avoided.

KNOWLEDGE NEEDS

We need more information on the effects of various levels of grazing on the condition of grazing areas. This would provide a more informed perspective on the point at which further grazing becomes extremely detrimental.

FREQUENCY OF RECOMMENDATION

Rare.

COSTS TO VISITORS

Moderate. Visitors may be unable to graze stock in preferred locations. This follows from the fact that those places that are most overgrazed are often those that are most preferred. The option to bring in feed (and still camp in the area) reduces costs.

PRACTICE 66—KEEP STOCK OFF CAMPSITES AS MUCH AS POSSIBLE

DESCRIPTION	Never confine or allow stock to roam on the campsite. They should be kept some distance away—where they will not foul the site. If necessary, bring them onto the campsite to be quickly loaded or unloaded. If they relieve themselves during this period, be careful to remove the manure.
SAMPLE MESSAGE	"Stock are never kept in camp. They are tied some distance away." (19)
PROBLEMS ADDRESSED AND RATIONALE	(1) Deterioration of established campsites and (2) visitor conflict. Stock can cause severe trampling damage if allowed on campsites (Cole 1983b). They also leave manure, which greatly reduces the desirability of the campsite to many visitors. These sources of impact are unnecessary if stock are kept away from the site.
IMPORTANCE	High. Stock cause severe ecological and esthetic impact to campsites. This practice effectively limits this problem.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Low. This practice requires some planning and coordination to load and unload stock quickly and move them off site. Behavior is not greatly constrained, however.

PRACTICE 67—KEEP LENGTHS OF STAY AT ONE PLACE SHORT

DESCRIPTION	Move to another campsite before forage is overgrazed and before places where stock are confined show excessive trampling damage. In fragile areas and during particularly vulnerable times of the year this may mean moving every day. In places with abundant forage and durable sites for confining stock, long stays are acceptable. Check with the managing agency about forage conditions.
SAMPLE MESSAGE	No examples of this precise recommendation were found, although some of the idea is captured in the following: "Avoid prolonged stock grazing in one area; it can have a serious impact on vegetation." (82)
PROBLEMS ADDRESSED AND RATIONALE	(1) Deterioration of established campsites, (2) proliferation of campsites, (3) deterioration of grazing areas, and (4) competition with wildlife. Grazing areas can sustain only a certain amount of grazing before long-term deterioration occurs (Strand 1979). Stock parties must move to another camp before this stage is reached. If the area is used frequently by other parties, or productivity is low, stays must be short to avoid deterioration and, in some places, competition with wildlife. Given the severe stresses caused by the trampling of stock, campsites can deteriorate rapidly unless stock are confined to highly durable sites. Particularly on previously unused or lightly used campsites, stays must be very short or highly impacted campsites will be created. Although less of a problem, long stays at established campsites can also cause excessive deterioration.
IMPORTANCE	High. Deterioration of grazing areas is one of the most widespread impacts in many wildernesses (Washburne and Cole 1983); stock impacts also are a major source of both excessive deterioration of campsites and the rapid proliferation of campsites. Although length of stay is probably less important than appropriate confinement of stock (see practices 71, 73, and 74 in particular), it is an important influence on amount of impact.
CONTROVERSIAL ELEMENTS	The general concept as stated here is not controversial. Any attempt to set quantitative limits on lengths of stay would be controversial because appropriate lengths of stay vary so greatly with such factors as previous impact, season, environmental conditions, and horse-handling practices.
KNOWLEDGE NEEDS	A better understanding of how much grazing different meadow types can sustain would help ascertain appropriate lengths of stay.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Moderate. This practice may require more frequent movement of camps than desired. This cost can be reduced by carefully planning to visit places that can support the lengths of stay desired. Also, by carrying supplemental feed and taking the time and care to confine stock properly, lengths of stay can be extended.

PRACTICE 68—WATER STOCK DOWNSTREAM FROM DRINKING SOURCES ON A DURABLE SPOT

DESCRIPTION	Pick a spot downstream from your camp and others in the vicinity to water your stock. Pick a spot that can handle the trampling, preferably a place with low banks that are hard and rocky or gravelly. Take stock to this place shortly after arriving in camp. Watering stock with a bucket can also reduce streambank impacts.
SAMPLE MESSAGES	"Horses should be watered downstream from the source of your drinking water and well away from the campsite area. When watering horses, avoid fragile streambanks and lake shore areas." (9) "Stock are led to water at a rocky spot where little bank damage will occur. Soft or marshy lake edges are avoided." (19)
PROBLEMS ADDRESSED AND RATIONALE	(1) Deterioration of grazing areas. The banks of water bodies are often steep and moist. These characteristics make these sites particularly prone to disturbance. Damage to stream and lake banks can be minimized by watering stock in places where banks are not steep and where soils are dry and hard. (2) Water pollution. Recreational packstock are a source of bacterial contamination of drinking water. Therefore, it is important to keep them out of waters to be used for drinking.
IMPORTANCE	Moderate. This practice can be effective in minimizing health hazards created by packstock and with the breakdown of banks. These are not among the most serious and prevalent wilderness problems, however.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Low. It may take additional time to show stock a durable place to water. But a major time commitment or shift in behavior is not required.

PRACTICE 69—CARRY AN APPROPRIATE AMOUNT OF WEED-FREE SUPPLEMENTAL FEED

DESCRIPTION	Bring some feed along so some of the grazing impact is reduced. This is particularly important when visiting either popular places or places where forage is limited. Feed should be weed free; processed feed avoids this problem. It is important to condition stock, before the trip, to eating small quantities of processed feed.
SAMPLE MESSAGES	"Plan on carrying supplemental feed for your stock. In many backcountry areas forage is limited and grazing may be restricted or unavailable. Inquire at the local Ranger Station about the conditions so that you will know how much supplemental feed to carry." (12) "Weed-free oats or pelletized feeds are preferable to hay, which is more bulky to pack. If hay is used it should be certified weed-free." (9)
PROBLEMS ADDRESSED AND RATIONALE	(1) Deterioration of grazing areas and (2) competition with wildlife. Overgrazing causes grazing areas to deteriorate and can remove forage needed by wildlife. Supplemental feed can reduce the dependency on forage, thereby reducing the likelihood of meadow deterioration and competition with wildlife. Exotic plants and weeds are a common problem in grazing areas. Weeds can spread into wilderness in feed for stock. To avoid this problem, feed should be either weed free or processed.
IMPORTANCE	Low to high. It is always important to keep weeds out of feed; however, weeds will also enter the wilderness on the body and hooves of stock. So use of weed-free feed will be only a partial solution to the problem. The use of supplemental feed is not important where forage is abundant and use levels are low. It is extremely important where forage is sparse and/or where use levels are high.
CONTROVERSIAL ELEMENTS	Packing in supplemental feed can make it necessary to bring in more animals. Thus, there is a tradeoff between the increased damage caused by more animals and the reduced damage resulting from less reliance on forage. As trips increase in length, the advantages of bringing in feed decline.
KNOWLEDGE NEEDS	A better understanding of the relationship between amount of grazing and deterioration would contribute to more useful guidelines about where supplemental feed is needed and a better perspective on the importance of supplemental feed.
FREQUENCY OF RECOMMENDATION	Uncommon.
COSTS TO VISITORS	Moderate to high. This can require the added cost of supplemental feed and the need to take more animals into the wilderness. Use of supplemental feeds can remove some of the hassles associated with proper grazing practices and finding campsites with sufficient forage.
SPECIAL SITUATIONS	A number of wilderness areas require all feed to be packed in. A number also prohibit the use of hay or unprocessed feed.

PRACTICE 70—PLACE FEED AND SALT ON A TARP OR IN A FEEDBAG OR CONTAINER

DESCRIPTION	Place salt blocks on a tarp, a notched log, or some other container. Keep salt off the ground. By using processed feed, with salt added, there is no need for supplemental salt. Supplemental feed should be placed in a nosebag or on a tarp. Do not place directly on the ground.
SAMPLE MESSAGES	"When feeding hay or grains that have been packed in, lay the hay out on a pack tarp or sheet of plastic." (9) "Supplemental feeds in cubes and pellets can be fed . . . in nose bags. [Salt blocks] are set out in a notched log or other container. This prevents rain from leaching salt into the soil, destroying vegetation, and attracting wildlife that paw up the ground." (19)
PROBLEMS ADDRESSED AND RATIONALE	Deterioration of grazing areas. If feed or salt is placed directly on the ground, stock or wildlife are likely to paw up and unnecessarily disturb the ground.
IMPORTANCE	Low. This is not one of the more significant causes of impact to grazing and camping areas.
CONTROVERSIAL ELEMENTS	None.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Low. Nosebags and tarps are all that is needed.

PRACTICE 71—MINIMIZE CONFINEMENT OF STOCK WHEN GRAZING; MOVE PICKETED STOCK FREQUENTLY

DESCRIPTION

Let stock graze freely, using hobbles if they need to be restrained. Avoid confining stock while they graze. If they must be picketed, move picket pins frequently—every few hours. Use metal pins rather than pins made from wood found on the site.

SAMPLE MESSAGES

"Restrained animals can do considerable damage by pawing and trampling the vegetation. Hobbles are the best device for restraining stock. The animal can move enough to graze but is not confined as in picketing." (9)

"Once in camp, travelers allow their stock to graze. Because picketing can cause considerable plant and soil damage, most stock is hobbled. Visitors picket only enough horses to keep the others from straying. Since they know it is illegal and environmentally improper to cut green trees, visitors carry metal picket pins for moving the horses easily two or three times a day." (35)

PROBLEM ADDRESSED AND RATIONALE

Deterioration of grazing areas. In addition to overgrazing of entire grazing areas, confinement of stock on part of a grazing area can cause substantial local deterioration. For this reason it is important to either allow horses to graze freely or, if they are picketed, to rotate stock frequently. This disperses grazing pressure and impact across a larger grazing area. Even with dispersal and rotation of grazing pressure, it is important not to overgraze the entire area by staying too long (practice 66).

IMPORTANCE

High. Careless confinement of stock is a primary source of impact in many places. Considerable damage can occur in relatively short periods of time. That is why confinement should be avoided as much as possible. When it cannot be avoided, it becomes necessary to invest considerable effort in frequently moving stock. Otherwise, serious deterioration will occur.

CONTROVERSIAL ELEMENTS

Some wilderness managers are more favorable toward picketing than others. This probably reflects their tradition of use. Meadow deterioration is likely to occur wherever stock is picketed, unless great care is exerted. Temporary corrals have also been suggested as a means of confining animals, particularly for long periods of time. This is likely to result in overgrazing of the corral area and, therefore, is not generally recommended.

KNOWLEDGE NEEDS

A better understanding of the effects of restraining stock in various ways for different periods of time would provide a better perspective on the importance of this recommendation. It would also provide more definitive guidelines on proper rotation frequency if using pickets.

FREQUENCY OF RECOMMENDATION

Rare (for minimizing confinement) to uncommon (for the need to frequently rotate picket pins).

COSTS TO VISITORS

Moderate to high. Costs are not substantial for well-trained stock and experienced stock handlers. Stock that are not well trained may run away if allowed to graze freely, and they may not handle hobbles well. If stock must be picketed, considerable time and effort must be invested in rotating animals before damage occurs.

PRACTICE 72—USE EXISTING HITCH RAILS AND CORRALS WHERE AVAILABLE

DESCRIPTION	In places where managing agencies have provided hitch rails or corrals for tying up stock, use these facilities.
SAMPLE MESSAGE	"Use existing camping and horse facilities when provided." (11)
PROBLEMS ADDRESSED AND RATIONALE	(1) Deterioration of established campsites and (2) proliferation of campsites. Hitch rails and corrals concentrate the impact caused by the confinement of stock. Stock is concentrated not only on certain campsites but also on one spot on these campsites. Where such facilities are provided but not used, stock impacts spread to other places. This can result in both the proliferation of sites damaged by stock and excessive deterioration of individual sites.
IMPORTANCE	High. Although horse-holding facilities are uncommon in wilderness, it is important that they be used when provided by the managing agency. At camping areas that are popular with stock parties, this is an effective way of limiting stock damage to a small area. Not using facilities defeats this strategy and results in unnecessary disturbance.
CONTROVERSIAL ELEMENTS	Most wilderness visitors are opposed to the provision of stock facilities in wilderness (Stankey and Schreyer 1987). This may reflect an assumption that they are being provided for convenience rather than resource protection and therefore are not appropriate. What we know about the nature of packstock impact suggests that, in popular places, concentrating stock is the most effective means of limiting inevitable disturbance (Cole 1983b). While many object to this strategy of concentrating impact in "sacrifice areas," the concept of using facilities where they are provided is not controversial.
KNOWLEDGE NEEDS	None.
FREQUENCY OF RECOMMENDATION	Rare.
COSTS TO VISITORS	Low. Most stock parties appreciate the convenience of using agency-built facilities.

PRACTICE 73—WHERE CONFINEMENT IS NECESSARY, USE A HITCH LINE ON A DURABLE SITE AWAY FROM WATER

DESCRIPTION

Stock should be allowed to run free (or with hobbles) as much as possible. If they must be tied up and confined, use a hitch line between two large trees. Use wide "tree-saver straps" (USDA FS 1981) to encircle the trees. Tie more than one horse to the line; this will tend to minimize idle pawing of the ground. Hobbling animals will also reduce pawing. Locate the hitch rail on a durable, hard site, preferably rocky or gravelly and without vegetation. It should be away from campsites (see practice 65) and from water. Never tie horses to trees for an extended period of time (see practice 74). Hitch rails and corrals are not necessary; they cause more disturbance than a hitch line.

SAMPLE MESSAGES

"Remember, any time stock is restrained, particularly if they are away from home and their special partners, they can cause considerable damage to trees, plants, and soil by pawing and tramping. If it is necessary to keep stock tied for any length of time, the following should be considered: (a) Use a rope hitch rail at least 200 feet from any water, trail, or campsite. (b) Select a site where they cannot tramp on tree roots and where damage to plants will be minimized. Rocky, hard ground is usually best. (c) If an animal is inclined to paw while tied, it can do considerable damage to the soil and plants. This type should be hobbled while tied. (d) If some horses are kept tied, while others are turned loose to graze at night or in the daytime, it is almost always best to keep two horses tied rather than one. Two will usually stand quieter." (18)

"A hitch line is a good idea. Stock can be quickly tied, kept in order, and easily watched. Wide nylon "tree-saver straps" with quick-adjusting buckles are used for speed and convenience. Rope is run between the straps, tied with a quick-release knot, and pulled taut." (19)

PROBLEMS ADDRESSED AND RATIONALE

(1) Deterioration of established campsites, (2) proliferation of campsites, and (3) water pollution. Confined stock can cause considerable damage to vegetation, soil, trees (if they are tied to trees), and water. The best alternative is to avoid confining stock. If they must be tied, it is important to select a location where disturbance will be minimized. Sites without vegetation and with a hard, rocky surface that cannot be churned up are best. It is also important to avoid disturbing campsites and to avoid contaminating water bodies. A hitch line is best because no native materials are used (as hitch rails and pole corrals do) and it minimizes the area disturbed; with corrals, a much larger area is disturbed.

IMPORTANCE

High. Disturbance caused by confined stock is a major source of impact on and around backcountry campsites. A few stock parties can cause substantial disturbance. Concentrating that impact on durable sites is the most effective means of limiting the problem.

CONTROVERSIAL ELEMENTS

Hitch rails, corrals, and trees are also used to confine stock. All of these practices cause more damage and are unnecessary.

KNOWLEDGE NEEDS

None.

FREQUENCY OF RECOMMENDATION

Uncommon.

COSTS TO VISITORS

Low. Attempts to avoid confinement entirely require more training of stock and higher risk of having stock stray. Using a hitch line in a proper location—as opposed to tying stock to trees or building a hitch rail or corral—is not much more difficult or time consuming.

PRACTICE 74—AVOID TYING STOCK TO TREES, PARTICULARLY SMALL TREES

DESCRIPTION

For breaks that last only a few minutes, it is acceptable to tie stock directly to trees—if they are larger than about 8 inches in diameter. Never tie stock to smaller trees and never tie stock to any tree for a long time. Use a hitch line between two trees instead (see practice 73).

SAMPLE MESSAGES

"To prevent tree damage, tie your stock to trees for only short rest periods." (33)

"When tying stock to trees the tree must be large enough to avoid rope damage to the bark. The diameter of the tie rope must also be large enough to avoid bark damage. Padding between the rope and the tree is recommended." (9)

PROBLEMS ADDRESSED AND RATIONALE:

(1) Deterioration of established campsites, (2) proliferation of campsites, and (3) general disturbance of natural conditions. Stock tied to trees can girdle and kill the tree, particularly if it is a small tree. When stock are tied to trees for long periods, they excavate wells around the base of trees, exposing and trampling roots. This practice seeks to avoid this unnecessary disturbance by suggesting alternative less-damaging practices (see practice 73).

IMPORTANCE

High. Tree damage and root exposure resulting from stock tied to trees is a pervasive problem on campsites. Using a hitch line instead is a simple way to avoid this problem.

CONTROVERSIAL ELEMENTS

None.

KNOWLEDGE NEEDS

None.

FREQUENCY OF RECOMMENDATION

Uncommon.

COSTS TO VISITORS

Low. The hitch line with tree-saver straps is a simple alternative to tying stock directly to trees.

PRACTICE 75—RENOVATE PAWED-UP AREAS; SCATTER MANURE; REMOVE PICKET PINS AND EXCESS FEED AND SALT

DESCRIPTION

In addition to normal camp cleanup, several of the disturbances unique to stock parties must be dealt with. Wherever stock have been, it is important to scatter manure and smooth over any pawed-up areas. If picket pins were used, they should be removed. If salt and feed are left over, they should be packed out.

SAMPLE MESSAGE

"And when it's time to break camp nothing is left behind. Temporary hitch rails and corrals are dismantled, and manure piles are scattered to aid decomposition, discourage flies, and as a courtesy to others." (19)

PROBLEMS ADDRESSED AND RATIONALE

(1) Deterioration of established campsites and (2) proliferation of campsites. This practice is intended to make established campsites attractive to subsequent users and to remove all evidence of your stay on previously unused sites. (3) Deterioration of grazing areas. Leaving picket pins encourages the next party to picket their stock in the same place; this quickly leads to overgrazing.

IMPORTANCE

Moderate. This practice can reduce the impacts associated with stock use; however, it is less critical than the practices associated with proper confinement and restraint of stock (practices 71, 73, and 74).

CONTROVERSIAL ELEMENTS

None.

KNOWLEDGE NEEDS

None.

FREQUENCY OF RECOMMENDATION

Uncommon.

COSTS TO VISITORS

Moderate. This requires some time and energy on the part of stock parties. That requirement is small compared with the time generally required for handling stock and can be considered a responsibility that must be accepted for the privilege of taking stock into the backcountry.

PRACTICES THAT CAN BE COUNTERPRODUCTIVE

The following four commonly recommended practices should not be generally recommended. They are likely to have more negative consequences than positive benefits.

1. VISIT WILDERNESS DURING LESS POPULAR DAYS OF THE WEEK AND/OR SEASONS

DESCRIPTION

Most people visit the wilderness on weekends and, in most places, during summer. Spring, winter, and fall can be particularly popular seasons in the South. Plan trips so that they fall during weekdays and less popular seasons of the year.

PROBLEM ADDRESSED AND RATIONALE

Too many encounters. Solitude tends to decline as the number of encounters between parties increases. The number of encounters is also strongly influenced by the number of parties in the wilderness at one time. Because this number is highly concentrated during certain seasons and days of the week (Roggenbuck and Lucas 1987), the number of encounters at more popular times could be reduced by encouraging more parties to shift their visits to less popular times. This would constitute shifting use from weekends to weekdays and from popular to unpopular seasons (in mountainous areas, for example, from midsummer to other seasons).

NEGATIVE CONSEQUENCES

Shifting use to seasons other than summer may involve shifting it to seasons when trails, meadows, and animals are more vulnerable to damage. Thus, this practice may conflict with practices 4 (avoid trips where and when soils are wet and muddy) and 5 (avoid trips where and when animals are particularly vulnerable to disturbance). Shifting use to weekdays and less popular seasons also can have the negative consequence of increasing encounter levels at these times. It is not clear how to evaluate the overall costs and benefits of simultaneously decreasing encounter levels at popular times and increasing encounter levels at other times. Visitors that seek out low-use times and expect to see few people are particularly vulnerable to the increase in encounters that is likely to accompany temporal shifts in use.

FREQUENCY OF RECOMMENDATION

Uncommon.

CONCLUSION

General recommendations to visit during less popular times of the year appear to have more potential costs than benefits. Information about use levels at various times might be given to visitors to help them make better-informed decisions—but not to attempt to influence their decisions. Even when providing information, it is important to suggest caution about use when the environment is fragile (such as during early season snowmelt) or when animals are vulnerable to disturbance (such as during winter).

2. AVOID VISITING MORE POPULAR PLACES IN THE WILDERNESS

DESCRIPTION

When planning a trip, select trailheads, trails, and destination areas that are not heavily used. Avoid places that are popular and likely to be "crowded."

PROBLEMS ADDRESSED AND RATIONALE

(1) Too many encounters. Shifting use away from popular places should reduce the number of encounters in these places. If the shift is pronounced enough, opportunities for solitude should improve in popular places. (2) Deterioration of grazing areas. Reduced grazing of popular forage areas would reduce the prevalence and severity of overgrazing. (3) Human waste. Reduced use of popular places without toilets could reduce problems with accumulation of human waste. A number of other problems, such as trail and campsite deterioration and wildlife impacts, might be reduced in popular places by this practice; however, the practice would be relatively ineffective because there is only a weak relationship between these problems and amount of use.

NEGATIVE CONSEQUENCES

Visitor use that is shifted away from popular trails and destination areas will go elsewhere. This can result in the creation of problems in places that did not have problems before. Virtually all types of problems—trail and campsite deterioration and proliferation, litter, increased encounter levels, and wildlife impact problems—are likely to increase. Negative consequences in currently little-used places are likely to outweigh positive benefits in popular places. Both loss of solitude and increase in ecological impact are greater where use levels increase from low to moderate than where they increase a similar amount, but from moderate to high levels (Cole 1987b; Stankey 1973). This suggests that the increase in problems created by increased use of little-used places is likely to be much greater than the reduction of problems caused by decreased use of popular places. In addition, the number of places where new problems are likely to develop is likely to be greater than the number of places at which problems will be reduced. Moreover, the currently little-used places are the ones that come closest to meeting the ideals laid out in the Wilderness Act; their integrity should not be sacrificed in order to reduce problems elsewhere.

FREQUENCY OF RECOMMENDATION

Uncommon.

CONCLUSION

In most situations, general recommendations about visiting less popular places are likely to be counterproductive. It is not clear that this practice will alleviate problems substantially in popular places; there are more effective ways to deal with most problems (such as requiring supplemental feed for stock, providing toilets, and selecting "out-of-the-way" campsites). Moreover, it is likely that problems will be created in currently little-disturbed places. There are situations, however, where it is appropriate to divert use from specific overused places to identified alternative use locations (Roggenbuck and Berrier 1981; Thornburgh 1986). This could be particularly useful in avoiding wildlife impacts—by advising people to stay away from or to not camp in certain critical habitats or places (such as in meadows in general or at a specific critical meadow).

3. BUILD FIRE IN A HOLE CUT IN SOD

DESCRIPTION

Build a campfire in dense vegetation by digging a pit, through the sod, down to mineral soil. Remove the plants in as large a block as possible and place them and the soil some distance from the pit. Dig the pit as deep as the plants' roots and keep the pit sides as vertical as possible. Make the pit large enough to avoid burning the surroundings. Patting mineral soil around the perimeter of the pit and keeping the perimeter moist can also help avoid scorching. After having the fire and cleaning out ashes, replace the soil and sod, making sure there are no air pockets. Water the site and remove evidence of disturbance.

PROBLEM ADDRESSED AND RATIONALE

Proliferation of campsites. This practice is a means of building a campfire in dense vegetation, with minimal disturbance. Where disturbance is minimized, the probability of creating a new campsite is reduced.

NEGATIVE CONSEQUENCES

Without question, this practice is the best way to minimize campfire impacts in areas of dense vegetation. The probability of the practice being ineffective and leaving a fire scar is high, however. Vegetation can be severely injured while being moved, it can dry out while being stored, and it can fail to grow after being replaced. Campfires should be built in a place without dense vegetation or they should not be built at all.

FREQUENCY OF RECOMMENDATION

Uncommon.

CONCLUSION

This practice was advanced as a way to minimize campfire impacts in places with dense vegetation. The National Outdoor Leadership School, which was involved in the initial development of this procedure, no longer uses the technique. Reexamination of old fires revealed frequent lack of success. The simple solution to the problem of avoiding impact is to not camp on dense vegetation on nights when a campfire is desired.

4. DISPOSE OF HUMAN WASTE IN A LATRINE

DESCRIPTION	Dispose of human waste in a single latrine excavated to handle the human waste of the entire party.
PROBLEM ADDRESSED AND RATIONALE	Human waste. Latrines are basically informal toilets established to concentrate waste in places where use is heavy and adequate dispersal of catholes is difficult.
NEGATIVE CONSEQUENCES	The difference between a latrine and a toilet is that each group digs its own latrine. In popular camping areas, proliferation of latrines becomes as much of a problem as proliferation of catholes. Moreover, the concentration of human waste in a latrine dramatically slows decomposition rates and attracts animals that dig up the latrine. The result is that latrines create more of a health hazard than individual catholes.
FREQUENCY OF RECOMMENDATION	Uncommon.
CONCLUSION	Latrines are generally recommended for large parties in popular camping places. Ideally, toilets should be provided in places where latrines seem like a good idea. Where toilets are not provided, widespread dispersal of catholes (people may have to walk a long way from camp) is preferable to a latrine. The only other options are to go with a smaller group or to stay away from very popular camping areas. With few exceptions, digging a latrine will increase the health hazard.

PRACTICES THAT ARE APPROPRIATE ONLY IN CERTAIN SITUATIONS

The following eight commonly recommended practices are appropriate in certain situations, but are inappropriate elsewhere. In each case, readers are referred to a recommended practice that describes situations where the practice is not appropriate.

1. **SELECT AN ESTABLISHED CAMPSITE**. This practice is appropriate in popular places with well-impacted campsites; it is not desirable in little-used places (see practice 24).

2. **SELECT AN UNUSED CAMPSITE**. This practice is appropriate in little-used places; it is inappropriate in popular places with well-impacted campsites (see practice 23).

3. **DO NOT CAMP ON HEAVILY USED CAMPSITES**. This practice is appropriate in little-used places; heavily used campsites should be used in popular locations (see practice 23).

4. **DISPERSE ACTIVITIES ON CAMPSITES**. This practice is appropriate when camping on previously unused sites in little-used places; it is not appropriate when camping on established, well-impacted campsites (see practice 32).

5. **CONCENTRATE ACTIVITIES ON CAMPSITES**. This practice is appropriate when camping on established, well-impacted campsites; it is not appropriate when camping on unused sites (see practice 34).

6. **BUILD FIRE IN AN EXISTING FIRERING**. This practice is appropriate when camping in popular locations with well-impacted campsites; it is inappropriate when camping in little-used places (see practice 42).

7. **AVOID BUILDING FIRE IN AN EXISTING FIRERING**. This practice is appropriate when camping in little-used places; it is inappropriate when camping in popular places with well-impacted campsites and established fire sites (see practice 41).

8. **DISMANTLE ALL FIRERINGS**. This practice is appropriate in little-used places and on little-impacted sites; it is inappropriate on established campsites that are likely to be used by other parties (see practice 49).

DEVELOPING LOW-IMPACT MESSAGES

The preceding section described each recommended practice individually. When putting together a low-impact message, it will be more effective to group individual practices and to weave discussions of rationale into statements of recommended practices. This makes it easier to convey the way of thinking and the ethic that is the ultimate goal of low-impact education.

Considerable creativity and writing skill are required at this stage. One example of an attempt to convey this way of thinking is the 1986 revision of the National Outdoor Leadership School's (NOLS) Conservation Practices (see appendix C). This revision was a cooperative effort between NOLS and the author to develop a set of recommended practices and rationale that incorporates the best available information. Other examples can be found in books—such as Hampton and Cole (1988) and Hart (1977)—and journal articles—such as Curtis (1982) and Wallace and DeBell (1982).

Tailoring the Message to Different Environments

The recommendations described in this report are general ones that apply across a range of different environments. Often, specific information is available about different environments that can make recommendations more effective. For example, in deserts, sand washes are among the most durable surfaces, while soils crusted with cryptogams (moss, lichen, algae, and fungus) are among the most fragile. At high altitudes snowfield turfs are durable, while heaths are quite fragile. The specificity of recommendations can be increased by developing different messages for different environments. In addition, the importance of various practices differs between environments. For example, campfire practices designed to avoid excessive use of firewood are particularly important in environments with low wood productivity,

such as timberline forests or deserts. Certain environments also offer unique opportunities for minimizing impact. For example, on coastlines, the effects of fires built below high tide will be removed by periodic tides. Low-impact guidelines for (1) deserts, (2) high altitude and high latitude areas, (3) travel on snow and ice, and (4) coastline areas have been developed for use in conjunction with the general NOLS Conservation Practices. These guidelines are presented in appendix D as examples of how general practices might be modified in certain environments. Similar guidelines might be developed for other environments, such as swamps or eastern forests.

Tailoring the Message to Different User Groups

Different types of users also present particular challenges and offer unique opportunities for minimizing impact. Stock users, for example, must be much more cautious than backpackers if they are to keep impact to low levels. Rafters and stock users, because they can carry specialized equipment, have the opportunity to reduce their impact to extremely low levels. Low-impact messages should be tailored to take advantage of these differences. There is no reason to burden backpackers with information about low-impact stock or raft use. Special considerations for some important user groups follow. Similar guidelines might be developed for other user groups, such as day hikers, anglers, and hunters.

Stock Users—Parties traveling with stock are particularly prone to causing problems with (1) deterioration of constructed trails, (2) creation of new trails, (3) deterioration of established campsites, (4) creation of new campsites, (5) visitor conflict, (6) deterioration of grazing areas, and (7) competition with wildlife. This potential reflects the greater bearing weight of stock, the tendency for shod hooves to churn up soil, the trampling damage associated with confining stock, and the consumption of forage by grazing stock. Key elements to low-impact stock use are care in grazing and in confining stock. It is also preferable for stock parties to keep to constructed trails and substantially impacted camping areas (which are able to tolerate use by stock parties without further deterioration), except where they are prepared to be especially careful. Practices specific to parties with stock were described in detail in a previous section.

Boaters—Rafters, and to a lesser extent kayakers and canoers, can carry fire pans (to shield the soil from campfire impacts), charcoal briquets (to avoid having to collect firewood), portable toilets (for removing human waste), and containers (to carry out ash and charcoal from campfires). Boaters often can also minimize their impact by camping below the annual high water line. These environments are often quite resistant, and much of the impact that does occur is removed by yearly floods. For these reasons, boaters should generally cause less impact than other users (if they take advantage of these opportunities).

Large Parties—Large parties are particularly prone to causing problems with (1) enlargement of established campsites, (2) creation of new trails, (3) creation of new campsites, and (4) visitor conflict. Practices 26 (select a site that is large enough to accommodate your party) and 32 (confine tents and activities to already impacted areas) are critical to avoiding campsite enlargement. Advance planning to identify places with sufficiently large campsites is needed. The three latter problems can be avoided by breaking the party up into smaller groups for traveling and camping. These smaller groups can spread out. On trails, this will reduce the conflict that results when large parties are encountered. Off trails, smaller groups are less likely to create a new trail, particularly if they spread out when walking (practice 19). At little-used camping areas, groups should stay separate, except to meet on some durable spot. This separation, along with spreading out tents and activities (practice 34), should reduce the likelihood of new campsites developing.

Parties Planning To Have Fires—Parties planning to have wood fires must be more cautious than those that do not. All of the practices in the section on campfires (practices 37-50) apply only to these users. Such parties must use particular caution when camping in little-used places because it is so important to camouflage any disturbance (practice 36). It is easy, when having a campfire, to leave a long-lasting scar. Such evidence tends to attract subsequent use, a tendency that often results ultimately in the creation of new campsites.

Parties Traveling Cross Country—Established trails are designed to accommodate use with minimal problem; well-impacted campsites function in the same way. Parties that choose to travel cross country and camp in little-used places accept special responsibilities for low-impact use (practice 6). Undisturbed places can experience long-term damage very quickly. Large parties, parties with stock, and parties planning to build campfires must be particularly careful in such places. Much more knowledge and decision-making ability are

required to select cross-country routes (practice 21) and campsites (practice 27) that can be used without leaving evidence of your passage. More care is also needed to spread out when hiking (practice 19) and camping (practice 34). Lengths of stay on campsites must also be short (practice 35).

Backcountry travel and campsite selection and behavior techniques differ so greatly between trail users and cross-country hikers that separate materials might be worked up for each type.

Tailoring the Message to Different Audiences and Media

It should be obvious that there is a large amount of information on low-impact use that must be communicated to visitors. The information in the NOLS Conservation Practices (appendix C) takes 10 single-spaced pages. Clearly, all of this information cannot be communicated to users with signs or even by information specialists at trailheads. Pamphlets, books, video demonstrations, workshops, and ranger contacts are all needed. We need to (1) decide which media are most effective for which messages, (2) identify the most effective media for different audiences, and (3) ultimately get all messages across effectively to all users. Messages need not only to *communicate*, but also to *motivate* visitors to adopt recommendations.

Unfortunately, information on how to communicate and motivate visitors is limited. A variety of educational media have been employed, but effectiveness has seldom been rigorously evaluated. Moreover, there has been little attempt to apply existing theory to this problem. A major research effort is needed to develop effective means of instilling a low-impact ethic.

Despite the importance of the topic, I will not attempt to summarize what is known about how to communicate with backcountry users. A major report, comparable in length and detail to this one, is warranted. Interested readers are referred to several articles that describe educational programs (Bradley 1979; Hart 1980) and a comprehensive review of alternative communication methods (Martin and Taylor 1981). Other worthwhile sources include Fazio's (1979) and Roggenbuck and Berrier's (1981) work evaluating the effectiveness of communication techniques ,and Dustin's (1985) attempt to bring psychological theory to bear on the question of how to instill a wilderness ethic.

RESEARCH GAPS

In the "knowledge needs" category under each practice, a number of research gaps were identified. These gaps are listed below, along with brief descriptions. They are listed in an approximate order of priority, starting with those that will most improve the application of practices.

1. *The durability of different environments.* We need to evaluate the durability of different environments as places for off-trail hiking, low-impact campsites, campfire sites, and holding stock. This is a broad topic. A fair amount is already known (Cole 1987b; Kuss 1986), and we will never have all the answers; however, it is important to continually increase our knowledge. This topic is assigned highest priority because this is knowledge that should be used continually by backcountry users and it is capable of substantially reducing impact.

2. *Harassment and disturbance of animals.* We need to learn how serious animal disturbance is. We need to learn which species are affected, where and when disturbance occurs, and how behavioral alteration can reduce problems. This is a broad topic about which very little is known (see Boyle and Samson 1983 for an annotated bibliography). Although we do not know enough to be certain, it is likely that adoption of disturbance-avoiding behavior could reduce impact substantially.

3. *Impacts of packstock on grazing areas.* We need to learn more about the effects of grazing and trampling on meadows and grasslands. We need to understand the effect of differences in the amount, timing, frequency, and location of grazing. This would be useful in developing better guidelines for avoiding overgrazing, recommended maximum lengths of stay, and the need for supplemental feed. This topic is a broad one about which little is known.

4. *Water pollution problems.* We need to know more about the nature, severity, and causes of recreation-related water pollution. To what extent does camping close to lakes and other water bodies cause problems? Is soap or fecal contamination of waters a common problem? We know very little about recreational impacts on water in wilderness (see Herrmann and Williams 1987 for a review). Research results may not change recommended practices, but it is critical to evaluating the importance of practices taken to avoid problems.

5. *Visitor preferences for campsite attributes.* We need to know more about the attributes that visitors seek when selecting a campsite. Tradeoffs between attributes are often required. Recommendations that visitors seek campsites away from lakeshores are based on an assumption that visitors are willing to give up camping by a lake for more solitude away from the lake and the opportunity to visit less disturbed lakeshores. Is this assumption, and others that we make about visitor preferences, valid? We know a fair amount about certain visitor attitudes and preferences (Stankey and Schreyer 1987), but we know little about how they make tradeoffs. This knowledge is important to recommendations related to behavior intended primarily to maintain quality visitor experiences.

6. *Sources of visitor conflict.* We need to know more about behaviors that result in conflict between parties. We know that certain visitors object to large parties, parties with stock, and parties with pets. The prevalence of these sentiments and means of mitigating conflict should be explored. The importance of other sources of conflict—shooting guns, competitive events, and so on—should also be examined.

7. *Relationship between quality of experience (visitor satisfaction) and frequency of encounters.* Although frequently studied, this relationship remains poorly understood. The aspect of this relationship most relevant to low-impact practices is whether or not the positive benefits of fewer encounters in popular places and at popular times exceed the negative consequences of more frequent encounters elsewhere and at other times. These changes are likely results of attempting to shift use away from popular places and times.

8. *Relationships between campsite impact and use frequency, length of stay, and party size.* We need to learn, for different environments, how much use sites can support before concentrating camping on a few well-impacted campsites becomes a more effective strategy than dispersing use among many undisturbed sites. Related to this is need for a better understanding of how rapidly impact is caused by parties of various sizes. This would be useful in recommending more specific length-of-stay and party size limits. Much is already known at a general level about these relationships (see Cole 1987b for a review). More quantification is needed for specific vegetation types. While this is likely to improve specificity, the basic concepts presented in the practices should be relatively unaffected by results.

9. *Seasonal variation in vulnerability.* We need to learn, for different environments, for different parameters (such as soil and animals), and for different sources of impact (such as stock and hikers), how vulnerability varies seasonally. We also need to learn how much variation there is in seasonal differences from year to year. We need to learn how to evaluate and predict vulnerability so visitors can vary their routes and/or behavior to account for seasonal differences. We have some general knowledge about seasonal vulnerability (such as that soils are particularly vulnerable during spring snowmelt), but more specific information is needed

10. *Campfire impacts and the effectiveness of alternative campfire construction techniques.* A better understanding of the nature and significance of the impacts associated with collecting firewood and burning it in campfires would help in evaluating the importance of campfire practices and deciding where particular care is needed (Cole and Dalle-Molle 1982). Tests of the effectiveness of various campfire construction techniques could improve recommendations about how to build low-impact campfires.

11. *Fecal decomposition rates.* We need a better understanding of how rapidly feces and pathogenic organisms decompose and how decomposition rates can be maximized. Certain microsites might prove to be better sites for decomposition than others. A better understanding of decomposition rates might indicate where toilets are needed and how widespread the dispersal of catholes must be. Some limited research suggests that we have not shown enough concern about disposal of human waste (Temple and others 1982)..

12. *How type of sole influences amount of impact.* It is widely assumed that lug-soled boots cause more damage than soft-soled boots, particularly on campsites. No studies have succeeded in demonstrating a substantial difference between sole types. Although a relatively minor point, further research might corroborate the general recommendation to wear soft-soled shoes around camp.

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APPENDIX A . LIST OF RECOMMENDED PRACTICES

I. TRIP PREPARATION

A. Clothes and Equipment

1. Choose clothing and equipment colors that blend with surroundings
2. Carry appropriate equipment

B. Party Size

3. Keep party size small

C. Where and When to Visit the Backcountry

4. Avoid trips where and when soils are wet and muddy
5. Avoid trips where and when animals are particularly vulnerable to disturbance
6. Avoid off-trail travel unless prepared to use extra care

II. GENERAL CONDUCT

A. Pets

7. Keep pets under restraint or leave them at home

B. Noise Levels

8. Be quiet in the wilderness

C. Disturbance of Natural and Cultural Features

9. Minimize disturbance of natural features
10. Do not disturb cultural artifacts or archaeological sites

D. Disturbance of Animals

11. Avoid harassment of animals
12. Do not feed animals
13. Protect food from animals

III. BACKCOUNTRY TRAVEL

A. Practices When Traveling on Existing Trails

14. Avoid walking on closed trails and/or developing user-created trails
15. Walk single file and keep to the main tread
16. Do not shortcut switchbacks
17. Take trailside breaks off trail on a durable site
18. Step off the trail, downslope, when encountering a stock party

B. Practices When Traveling Off Trail

19. Spread out when walking off trail
20. Do not mark cross-country routes
21. Choose a cross-country route that crosses durable surfaces
22. Use caution when ascending or descending steep slopes

IV. CAMPSITE SELECTION AND BEHAVIOR

A. Guidelines for Campsite Selection

23. In popular locations, select a well-impacted campsite
24. In remote locations, select a previously unused campsite
25. Never camp on a lightly impacted campsite
26. Select a site that is large enough to accommodate your party
27. Select a durable site
28. Select a concealed campsite away from trails, occupied campsites, lakes, and other water bodies

B. General Campsite Behavior

29. Wear soft-soled shoes around camp
30. Minimize intentional site alteration and the building of structures
31. Avoid trampling vegetation

C. Campsite Behavior on Well-Established Campsites
   32. On established campsites, confine tents and activities to already impacted areas
   33. On established campsites, dismantle any structures you built and any other inappropriate structures; leave the site clean and attractive

D. Campsite Behavior on Previously Unused Sites
   34. On previously unused sites, disperse tents and activities
   35. On previously unused sites, keep lengths of stay short
   36. On previously unused sites, camouflage any disturbance

V. CAMPFIRES

A. Places Where Campfires Are or Are Not Appropriate
   37. Limit the use of campfires
   38. Avoid fires where firewood is not plentiful
   39. Do not build a fire where fire danger is high
   40. Build fires on mineral soil where trees, roots, vegetation, or rocks will not be scarred
   41. In places with well-impacted campsites, build fires in existing firerings or on fire scars
   42. In places without well-impacted campsites, do not use existing firerings or scars; dismantle any rings

B. Firewood Gathering
   43. Gather firewood away from camp; disperse your gathering
   44. Use only dead and down firewood that you can break by hand

C. Fire Site Construction on Previously Unused Sites
   45. On previously unused fire sites, build fire in a shallow pit or on a mound of mineral soil
   46. Do not ring a fire with rocks

D. Campfire Use and Cleanup
   47. Keep fires small
   48. Burn charcoal to ash; soak ashes; scatter excess firewood
   49. On preexisting fire sites, leave the firering clean and attractive; dismantle extra firerings
   50. On previously unused fire sites, remove all evidence of the fire

VI. WASTE DISPOSAL AND SANITATION

A. Disposal of Litter and Organic Wastes
   51. Pack out nonorganic litter (or burn readily burned litter)
   52. Pick up other people's litter
   53. Pack out or burn organic garbage (or scatter fish viscera)

B. Disposal of Human Waste
   54. Use toilets if provided
   55. Dispose of human waste in a properly located cathole

C. Bathing and Washing
   56. Use biodegradable soap in small amounts, if at all
   57. Bathe, wash, and dispose of waste water away from water bodies and campsites

VII. ADDITIONAL PRACTICES FOR PARTIES WITH STOCK

A. Equipment and Trip Preparation
   58. Use properly trained stock
   59. Carry appropriate equipment
   60. Minimize the number of stock

B. Practices When Traveling on Existing Trails
    61. Stock should stay on established trails as much as possible
    62. Remove trail obstacles instead of skirting them
    63. Lead stock on the trail, rather than loose-herd them
    64. Tie stock off trail, on a durable site, when taking a break

C. Campsite Selection
    65. Avoid places that have already been heavily grazed

D. Campsite Behavior
    66. Keep stock off campsites as much as possible
    67. Keep lengths of stay at one place short

E. Watering, Feeding, and Grazing Stock
    68. Water stock downstream from drinking sources on a durable spot
    69. Carry an appropriate amount of weed-free supplemental feed
    70. Place feed and salt on a tarp or in a feedbag or container
    71. Minimize confinement of stock when grazing; move picketed stock frequently

F. Confining Stock
    72. Use exisiting hitch rails and corrals where available
    73. Where confinement is necessary, use a hitch line on a durable site away from water
    74. Avoid tying stock to trees, particularly small trees

G. Cleanup
    75. Renovate pawed-up areas; scatter manure; remove picket pins and excess feed and salt

APPENDIX B: SOURCE MATERIALS ON LOW-IMPACT PRACTICES

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APPENDIX C: NOLS CONSERVATION PRACTICES

If we are to maintain the ecological integrity and quality experiences that backcountry provides, it is imperative that every visitor strives to minimize his/her impact both on the land and on other visitors. Otherwise management of backcountry will become increasingly dominated by rules, regulations, and restriction of access and use. The National Outdoor Leadership School has pioneered the teaching and development of practical conservation techniques, designed to minimize impact, since 1965.

We recommend the following practices as a guide to minimizing the impact of your backcountry visits. This guide represents a synthesis of our observations and experience with human impact in the backcountry, as well as the results of research on recreational impact and its causes. Under each major topic, we briefly discuss factors to consider when making judgements about how to minimize impact and the rationale behind recommended practices. These sections are followed by a list of specific practices.

NOLS welcomes comments and suggestions for further modifications to these conservation practices. Before traveling into the backcountry, we recommend that you check with local officials of the Forest Service, Park Service, Fish and Wildlife Service, Bureau of Land Management, or other managing agency for advice and regulations specific to the area.

Minimum impact backcountry use is an ethic and way of thinking. It depends more on attitude and awareness than on rules and regulations. Conservation practices must be flexible and tempered by judgement and experience. Consider the variables of each place—soil, vegetation, wildlife, moisture level, the amount and type of use the area receives and the overall effect of prior use—then use these observations to determine which recommended practices to apply. Minimize your impact on the land and on other visitors, but be sure to enjoy your visit as well.

A. BACKCOUNTRY TRAVEL

When traveling in the backcountry, care is required to minimize disturbance of both other visitors and the environment. Disturbance of other visitors is minimized when contacts are infrequent, party size is small, and behavior is considered appropriate by others. Impacts on wildlife, soil and vegetation can be minimized by walking on constructed trails that are already highly disturbed and, in many cases, have been designed to accommodate heavy use. Unfortunately, use of existing trails increases contact with other visitors. Consider the trade-off between social and ecological impacts when deciding whether to travel by trail or cross country. The impacts associated with cross country travel are minimized when group size is small, routes are carefully selected to avoid fragile terrain and critical wildlife habitat and special care is taken to avoid disturbance.

Specific practices are as follows:

1. Travel quietly in the backcountry, whether hiking by trail or cross country. You will be more aware of your environment, wildlife will be less disturbed, and other visitors will appreciate the solitude.

2. Brightly colored clothes and equipment have limited advantages in the backcountry, despite their great appearance in store windows. To minimize the likelihood that others will see you and your camp, attempt to wear and carry earth colored clothes and equipment, particularly tents.

3. If you are camping with a large group, hike in groups of no more than 4-6 people. Four is an optimum number, especially for cross country travel, because in case of sickness or injury one person can stay with the victim while two people go for help. A group of four is small enough to minimize impact on other visitors and on the environment when traveling cross country. Use judgement in breaking your group into smaller units to minimize impacts and maximize individual enjoyment and self-reliance.

4. If possible, visit the backcountry during seasons or days of the week when use levels are low. This should be tempered with a concern for avoiding travel when the environment is particularly fragile (for example, during snowmelt when trails are muddy). Similarly, by visiting places that receive little use, contact with others will be minimized. Again, this should be tempered by a concern for avoiding disturbance of such little-used and little-impacted places. Large groups can disturb these places rapidly.

5. Pick up all of your litter and any of that left by others that you can. On the way out—when your pack is light—try to pick up a little extra.

6. Allow others a sense of discovery by leaving rocks, plants and other objects of interest as you found them. Enjoy an occasional edible plant, but be careful not to deplete the surrounding vegetation or to disturb plants that are either rare or do not reproduce in abundance (such as many edible lilies).

7. Respect the needs of birds and other animals for undisturbed territory. When tracking wildlife for a photograph or a closer look, stay downwind, avoid sudden movement, and never chase or charge <u>any</u> animal. Avoiding disturbance is particularly important at birthing or nesting sites and at watering or feeding grounds, especially during times of year, such as winter, when animals are already stressed. Find out as much as you can, before entering the area about species, places and times when disturbance is likely. Some animals may be quite curious, but resist the temptation to feed them. Even in low-use areas, feeding wildlife can alter feeding habits, migration patterns and reproduction levels, ultimately resulting in unnatural behavior, population structure and species composition.

8. When following existing trails, walk single-file on the designated path. Walking outside the tread, to walk abreast or to avoid rocks or mud, breaks down the trail edge and widens the trail. It can also lead to the development of multiple trails. As with muddy stretches, snowbanks should be crossed, rather than skirted, to avoid creation of additional paths. Shortcutting switchbacks causes erosion and gullying. If a trail is impassable, walk on hard surfaces (such as rock, sand or snow) as much as possible and notify the agency officials responsible for that area.

9. When taking a break along the trail, move off the trail some distance to a durable stopping place. Here you can enjoy more natural surroundings and other parties can pass by without contact. Durable stopping places include rock outcrops, sand, other non-vegetated places and sites with durable vegetation, such as dry grasslands.

10. When you meet a stock party on the trail, allow them plenty of room, as stock are frightened easily. The entire party should move off to the same side of the trail, if possible the downhill side, and stand quietly until the stock party passes. Sometimes it helps to talk, in a low voice to the first rider, so the horses have advance notice of your presence.

11. Cross country travel is acceptable if groups are small (no larger than 4-6) and fragile areas can be avoided. Cross country travel is undesirable where user-created trail systems are developing, in wet places, on steep and unstable slopes, on crusted desert soils and in places where wildlife disturbance is likely. It is most desirable on rock, sand, snow and ice or stable non-vegetated surfaces.

12. When traveling cross-country it is generally best to spread out rather than have everyone follow the same route. This will minimize the amount of trampling any place receives and avoid the creation of undesired trails. In some places it is not practical to spread out; avoid such routes if other groups are likely to follow in your footsteps and particularly if incipient paths are developing. In extremely fragile places, such as on cryptogam soils, it is best to walk single-file so only one trail is created. Cross-country travel should be avoided in such fragile places.

13. Do not blaze trees, build cairns or leave messages in the dirt. Such markers may be confusing and they detract from other visitor's sense of discovery.

14. In steep terrain it is least damaging to ascend or descend on rock outcrops or snow. On soil-covered surfaces it is less damaging to ascend than to descend steep slopes. If slopes are so steep that it is necessary to dig toes and heels into the soil to get a grip, some other route should be located, if possible. Spreading out can also reduce damage. When descending loose scree slopes, move slowly and cautiously. Rapid descents can move sizeable quantities of scree downslope. This erosion is undesirable and should be minimized.

15. If traveling with pets (this is prohibited in many National Park Service areas and discouraged in many other areas), keep them under restraint. They should never be allowed to chase wildlife or harass other users and barking should be discouraged. Pets should be left at home.

B. CAMPSITE SELECTION AND USE

Selecting an appropriate campsite is probably the most difficult and perhaps the most important aspect of low impact backcountry use. It requires the greatest use of judgement and information and often involves making trade-offs between minimizing ecological or social impacts. A decision about where to camp should be based on information about the level and type of use in the area, the fragility of vegetation and soil, the likelihood of wildlife disturbance, an assessment of previous impacts and your party's potential to cause or avoid impact.

In selecting a campsite, the objective is to choose one that will not be damaged by your stay. Generally it is best to camp either (1) on apparently undisturbed sites (if your stay will cause little impact and, therefore, not encourage subsequent use by other parties) or (2) on sites that are so highly impacted that further use will cause no additional impact. Lightly impacted sites—those that have obviously been used but with a substantial amount of vegetation surviving on-site—should always be avoided; such sites will deteriorate rapidly with further use, while if unused they should recover rapidly.

When selecting an undisturbed site, choose one that either has no vegetation or a durable vegetation cover. When selecting a high impact site, choose one that is concealed and, if possible, in thick forest duff (the dark layer of decomposing leaves, needles and twigs that lies on top of the lighter, grittier mineral soil). On such sites, little vegetation can survive use, but exposure of mineral soil will be less pronounced on sites with thick organic horizons. If mineral soil exposure is minimal, soil compaction and erosion will also be minimized. Other considerations when selecting a site include camping away from critical wildlife habitat, particularly water holes, away from trails and other campers and, in popular areas, away from "beauty spots" and lakes and streams.

Appropriate camping behavior depends upon whether a pristine or a high impact site has been selected. On pristine sites it is best to spread out tents, avoid repetitive traffic routes and move camp every night. The objective is to minimize the number of times any part of the site is trampled. On high impact sites, tents should be concentrated on already impacted areas, as should traffic routes, and multi-day stays are acceptable. The objective is to confine impact to places that have already been impacted and avoid enlargement of the site.

Specific practices of, first, site selection and then camping behavior are as follows:

1. Obey any regulations in the area related to campsite selection. Select either a pristine site or a high impact one. A pristine site is one that shows no evidence of previous use. A high impact site is one on which vegetation has been removed from an area large enough to accommodate your group. Avoid selecting a pristine site in popular areas or a high impact site in an infrequently used area. Select a high impact site for large groups, multi-day stays or when you want to build a fire (if there is abundant firewood in the area). Allow enough time and energy to select an appropriate site.

2. Selection and use of pristine sites

   a. Select a site, well away from high impact areas, that shows no evidence of previous use and is unlikely to be used after you leave. Durability of the ground surface is the most important consideration in determining exactly where to set up tents and the "kitchen". Non-vegetated areas, such as slickrock, rock outcrops, gravel bars, beaches and snow, are best. Forest duff is acceptable if it is possible to not crush any plants or seedlings (forest-floor vegetation is highly fragile). Grassy areas and dry meadows can also make good pristine campsites. They are quite resistant and capable of recovering rapidly from the effects of one night of low-impact use. When deciding whether or not to camp in a meadow, consider whether you will impact other users or wildlife. Places to avoid, if possible, include vegetated forest-floors, sites with low-growing shrubs (particularly those at or above timberline), moist areas, and crusted desert soils.

   b. In setting up camp, disperse tent sites and the "kitchen" on durable sites. Wear "soft" shoes around camp. Minimize activity around the kitchen and places where packs are stashed and watch where you walk to avoid crushing vegetation. Take alternate paths to water and minimize the number of trips to water by carrying water containers. Avoid using the same general area for more than one night. Dispersal of sites, traffic routes and activities and short stays are particularly important for large groups, which must be especially careful not to disturb the site. When leaving, camouflage the area by covering any scuffed-up places with duff or other native materials (see under Fires and Stoves for more).

3. Selection and use of high impact sites

   a. Select a site that has already lost most of its vegetation cover. If possible, avoid those with obvious soil erosion and with root exposure and mutilations on most trees, as well as those that have coalesced into large campgrounds. Such sites are poorly located and/or have been used improperly in the past; they should probably be permanently closed to use. In very popular areas, however, use levels are so high that it is best to use these severely impacted sites. If possible, choose screened, forested sites, with thick organic horizons. Otherwise choose sites that naturally lack vegetation—those that are gravelly, sandy or have exposed mineral soil. Avoid camping in meadows and the zone between forest and snow. The visual impact of campsite deterioration is severe in

these particularly scenic areas. Avoid camping close to water sources, trails, other campers and "beauty spots". The choicest camping spots are often prime locations for other people's enjoyment of the area, so take a little extra time to seek out a more "out-of-the-way" site.

b. In setting up camp, do not sprawl out. Set up tents and the "kitchen" in places that have already been impacted, with well-developed paths between tents and the "kitchen". Avoid enlarging the site and try not to step on tree seedlings. When leaving camp, make sure that it is clean, attractive and will be appealing to the next group to use the area.

4. On all sites, leave the area as you found it. Do not dig trenches for tents, cut standing trees or branches or pull up plants or embedded rocks to make a pleasant camp. If you clear the sleeping area of surface rocks, twigs or pinecones, replace these items before leaving. On high impact sites, it is appropriate to clean up the site and dismantle inappropriate user-built facilities, such as multiple firerings, constructed seats, tables, etc. However, properly-located and legal facilities, such as a single firering in many areas, should be left. Dismantling them will cause additional impact, because they will be rebuilt, with new rocks, and impact a new area.

5. A backcountry camp should be organized. If you have laundry to dry or equipment to air out, make sure these items are not in sight of other campers or hikers, especially around lakeshores or in open meadows. Make sure your food is protected from animals. This is especially important in bear country.

C. FIRES AND STOVES

Fires should be used sparingly, as they are among the most serious visual impacts in the backcountry. They can also sterilize the soil locally and collection of firewood can scar live trees and snags and deplete large decaying wood in the soil. Large decaying wood plays an important and irreplaceable role in the ecosystem—in water and nutrient conservation and as a substrate for biological activity; smaller pieces of wood are less critical. Fires can also escape and burn large areas. Avoid use of fires when fire hazard is high. Finally, many areas have regulations that control the use of fire; be certain to know and respect regulations.

Use of stoves is always preferable to building a campfire. Always carry a stove; use it for most if not all cooking; and only build a fire where it is safe and will not cause further damage or deplete wood supplies. Campfires are acceptable at high impact sites in existing firerings or places where fires have been built—but only if there is abundant dead wood on the ground. Fires should be avoided in popular areas in the desert or near timberline, because wood regenerates so slowly in these places. On pristine sites, fires are less desirable. Although firewood may be abundant, fires on undisturbed sites can damage soil and vegetation, as can concentrated trampling around the fire. In popular areas there is no excuse for building a fire where one has never been built before. In remote places, impact can be minimized if fires are carefully constructed on sandy sites or sites with abundant mineral soil, or below the high water line along water courses or on the coast. With special care fires can also be built on rocks or in dense vegetation (see below for further description of techniques), but use of these latter techniques should be minimized.

When building a campfire on a pristine site, care must be taken in locating the fire, constructing it, selecting and burning wood, avoiding trampling around the fire and in cleanup. When building fires in existing rings on high impact sites, only care in selecting and burning wood and a moderate amount of cleanup is necessary.

Specific fire-building practices are as follows:

1. Locate campfires where they are safe, damage will be minimal and cleanup and camouflaging of the site will be easiest.

    a. Always build fires far from tents, trees, branches, root systems and large rocks that might be damaged by sparks and heat or blackened by smoke.

    b. When looking for a potential fire site in a pristine area, the usual types of surfaces to choose between are vegetation, rock, duff (the dark surface layer of decomposing leaves, needles and twigs) and bare mineral soil (the lighter and grittier soil layers beneath the duff). In order of preference, choose a surface of mineral soil, thin duff (less than 2-3 inches thick), sparse vegetation, or a flat rock. Never build a fire in thick duff because the danger of fire spreading is great. Avoid fires in dense vegetation because it is difficult to not damage the vegetation.

    c. On a previously-used site where fires have been built in several places, select the fire scar that is most pronounced and/or is in the best location (in terms of the criteria in a and b above). If you can, cleanup all other firerings and scars (see Practice 4b below). This cleanup will more than compensate for the effect of another fire on the site.

2. Construction. Fires can be built either on a mound or in a pit. Mound fires are preferable if an adequate supply of sand or mineral soil can be found without damaging the source area. Regardless of fire type or location, avoid blackening rocks by cooking on a stove, using a grill with folding legs, or hanging pots from a dead branch.

    a. **Mound fire**: Spread a layer of soil about 6 inches deep on top of the ground surface, over an area larger than the fire will occupy. Build the fire on the soil. Mound fires are most likely to be built on mineral soil, duff or rock.

    b. **Pit fire**: In mineral soil, simply dig a shallow pit, several inches deep. Build the fire in the pit. Where there is a thin duff layer or sparse vegetation, clear the duff down to mineral soil from a circle several feet in diameter; build the fire in a shallow pit in the center of the circle of mineral soil. If a fire absolutely must be built in dense vegetation, dig a pit down to mineral soil and as deep as the plant's roots, if possible. Keep the pit sides as vertical as possible. Make sure it is not so deep that air circulation is hindered. Remove the plants and soil in as large a block as possible and place them neatly some distance from the pit. Make sure the pit is large enough to avoid burning the adjacent vegetation. This can also be prevented by patting mineral soil around the firepit perimeter and by keeping the perimeter moist. The removed sod should also be kept moist.

3. Select firewood from small diameter wood lying loose on the ground. If wood is not small and dry enough to break by hand it should not be used. Do not bring saws or axes. Gather wood some distance from camp on existing sites and always leave some wood, so the area does not look denuded. Collect only enough wood for a small fire; do not stockpile. Avoid burning food scraps and plastic. Complete combustion is difficult, wastes wood and transfers large quantities of heat into the soil; incomplete combustion makes cleanup difficult.

4. Cleanup

    a. At least 30 minutes before finishing with the fire, begin to burn remaining wood and charcoal to ash. Heap coals and unburned pieces of wood where the heat is greatest and keep adding very small pieces of

wood until only white ash remains. Soak ash with water and crush any charcoal remnants to powder. Scatter any excess firewood away from the site.

b. If using a pre-existing fire site, leave a small clean firering to attract the next user. If large quantities of ash were generated by you or previous users, scatter it some distance from the campsite. Any excess blackened rocks—from an over-built firering or from multiple firerings—should be returned to their original locations, if possible, or scattered some distance from the camp.

c. If using a pristine site, scatter ash widely. If using a mound fire, scatter the soil and ash and camouflage the surface with mineral soil or litter and duff (whatever matches the surroundings). If the mound was built on a rock, rinse the rock off. If using a pit, fill it in and camouflage the site. For pits in dense vegetation, make sure there are no air pockets underneath or around sod blocks to cause drying of roots or subsequent settling of the soil. Water the site well to help recovery and landscape the area.

D. <u>SANITATION</u>

Proper disposal of human waste is difficult, particularly in heavily used areas where toilets are not provided. Only footprints are more difficult not to leave in the backcountry. The most important objectives when deciding on how to dispose of waste are (1) to minimize the chance that other people will find it, (2) to minimize the chance that waters will be polluted and (3) to maximize the rate of decomposition. In the past, objectives 1 and 2 have been met by recommending burial of feces in catholes or latrines (for large groups) well away from water bodies. The oft-stated contention has been that decomposition by soil organisms would be rapid. Unfortunately, recent research has found that this is not always the case. In the Rocky Mountains, pathogenic organisms survived in buried feces for a year or more. Moreover, survival was little affected by either depth of burial or the type of site where the feces was buried. It is still generally best to deposit feces in catholes, but the slow decomposition rate emphasizes the need to disperse catholes widely and far from water, campsites and other frequently used places.

Decomposition is most rapid when feces is left at the surface in the open sunlight. It is least rapid when concentrated (as in a latrine) or when deposited in soils that are cold, sterile or wet. Therefore, in remote places where there is little chance that others will find your feces, it may be desirable to leave it at the surface. In more popular places, it will be necessary to bury feces in catholes or, as a last resort (for large groups) to concentrate it in latrines. Considerable judgement must be exercised to determine if surface deposition is acceptable and whether to use a latrine or individual catholes.

Urination is less of a problem. It has little direct effect on vegetation or soil. It does attract salt-craving wildlife, however, and they can defoliate plants and dig up soil. Therefore, it is best to urinate on rocks and in places where urine is unlikely to attract wildlife.

The primary consideration with washing yourself or your clothes is to avoid contamination of water supplies.

Specific practices are as follows:

1. Only leave feces on the surface in low use areas, well away from trails, campsites and both perennial and seasonal water bodies. Choose a dry, open exposure that is unlikely to be walked over. Scattering and smearing the feces around will maximize exposure to the sunlight. Surface disposal is most desirable above timberline where digging holes or moving rocks can cause long-lasting impact.

2. In most situations, catholes are the preferred method of disposal. Choose a level spot and dig a hole, about 6 inches deep, in the organic soil horizon, where organisms are most abundant. Avoid wet areas and go at least 200 feet from trails, campsites and water bodies.

3. Latrines may be necessary for long stays by large groups in popular areas. Locate the latrine away from trails, camps and water bodies, on a well-drained forested site with thick organic horizons. Build it when you first arrive in camp and make sure that everyone knows where it is. Latrines should be at least 12 inches deep to minimize the chance that they will be dug up by animals or exposed by other people. After each usage, feces should be covered with soil and compressed with foot or shovel. This encourages decomposition. Fill in the latrine once it gets within about 4 inches of being full.

4. Minimize the use of toilet paper. If it is used, either pack it out (ideally) or burn it as completely as possible and bury any remnants. Do not burn toilet paper if fire hazard is high or if regulations prohibit it. Tampons should be packed out (unless you are in grizzly bear country) or burned in a very hot fire; they should never be buried.

5. It is best to urinate away from trails, campsites and water bodies. Areas with thick organic horizons and bare rock are the best sites.

6. Soap must not enter lakes or streams, so it is best to minimize its use. If bathing with soap is necessary, get wet; lather up on shore far from water; and rinse off far from water bodies with water carried in a pot. This procedure allows the biodegradable soap to break down and filter through the soil before reaching any body of water. Clothes can be cleaned by thorough rinsing. Soap is not necessary and residual soap can cause skin irritation. Avoid even rinsing in small water bodies.

E. <u>WASTE DISPOSAL</u>

The basic rule of waste disposal is to pack out what cannot be avoided by careful meal planning. Only waste water and fish viscera should be scattered and burning of waste should be minimized. Scattering of food remnants will attract wildlife and can alter feeding habits, migration patterns and reproduction levels. Although these effects are unlikely to be serious in remote places, it is always best to pack out scraps. Burial is ineffective because animals will dig up waste.

Specific practices are as follows:

1. Waste water, from washing dishes or excess cooking water, should be drained off either in the corner of a fire pit or away from water bodies and campsites (to prevent attracting flies). If there are large quantities of water, pour it into a sump hole or disperse it widely. Pick up food scraps and pack them out with excess food and other litter.

2. Litter and food scraps can be minimized with careful preparation. Food can be packaged in plastic bags, instead of cans, bottles or tin foil. Food can be carefully measured, so leftovers are minimized. When food is left, it should be packaged up and either eaten later or packed out. Partial burning, which is likely to occur when food is burned at the end of a meal, is unacceptable.

3. Fish viscera are generally a natural part of the ecosystem. They should be scattered widely, out of sight and away from campsites. In high use areas and in bear country they should be scattered a long way from camps. Do not throw viscera back into lakes and streams (unless bear danger is high and viscera can be thrown into deep water); the cool temperatures in most mountain waters prevent rapid decomposition.

APPENDIX D: NOLS REGIONAL GUIDELINES

1. DESERT CONSERVATION PRACTICES

Many desert environments appear largely sterile and lifeless, but this is deceiving. Most desert landscapes consist of dispersed islands of life and fertility in a matrix of largely barren rock and mineral soil. These fertile islands of vegetation, animals, decaying organic matter and structured soils develop beneath shrub and tree clumps. Although they may occupy only 10-20% of the ground surface, over centuries they become as structured, fertile and diverse as many humid environments. When these islands of vegetation and soil are disturbed, the results of centuries of biological cycling are destroyed and centuries will pass before recovery is complete.

Plant growth in deserts is limited by short supplies of water, a deficiency that is manifested in low resilience, the most unique characteristic of desert environments, relevant to conservation practices. Desert environments vary greatly in their ability to resist impact—some like cryptogamic soil are extremely fragile while others like sandy washes and slickrock are highly resistant; but all desert environments, except for those around water, recover very slowly once impact does occur. Because impacts are so long-lasting it is particularly important, in deserts, either to use an area in such a way that you leave no visual evidence of your visit (and do not disturb the fertile islands) or to use trails and campsites that are already highly impacted.

Riparian strips and areas around water holes contrast strikingly with other desert environments. In effect they are localized non-desert environments superimposed on the arid landscape. Riparian zones can often recover rapidly following disturbance; but their richer vegetation and soils can also be rapidly disturbed and these environments provide focal points for both wild animals and human visitors. Water is critical to the survival of wildlife and the enjoyment of visitors. Therefore, special attention must be paid to avoiding pollution of water sources and disturbance of the flora and fauna that depend on them, particularly where they are sparse.

Where water sources are sparse, social impact problems are aggravated by the tendency for all parties in any area to be attracted to and camp near the same water supply. Thus crowding problems can be unusually pronounced in desert environments.

Low resilience is one manifestation of the low productivity of deserts that results from a limited amount of water. Another manifestation is a slow rate of wood production. Therefore downed wood used for firewood is replaced very slowly. This makes deserts the least appropriate environment for fires, along with high altitude and high latitude environments.

Most desert environments can be used with relatively little impact, because resistant sites are usually abundant. The keys to low-impact are (1) to either confine activities to resistant surfaces or, where this is not possible or use is heavy, to travel on existing trails and camp on high impact sites, (2) to avoid disturbance of areas around water and not camp near water where supplies are scarce, and (3) to minimize use of wood for fires.

Backcountry travel

Practices are the same as the general practices, but several are particularly important and some of the details are unique to deserts. Because any scars you leave will be slow to heal, you accept a more profound responsibility when you choose to travel cross-country. Only travel cross-country where there are no established trails, there are durable routes on slickrock, along dry washes, or on non-vegetated ground (without cryptogam crusts), and you can be sure you will leave no evidence of your passage to attract others.

Cryptogam crusts are a particular concern. These crusts consist of free-living blue-green algae, fungi, lichens and mosses in a matrix of soil, that form conspicuous black pedestaled surfaces. These crusts have many functions. They increase soil stability, reducing the potential for both wind and water erosion; they increase the ability of soils to absorb rainfall and promote water conservation; they fix nitrogen and act as a nutrient reservoir for higher plants;

and they provide a preferred substrate for the germination and growth of plants. Unfortunately, just a few people walking across a crust will destroy the crust and leave a trail that will attract others. In cryptogam areas, stay on established trails or, if there is no alternative, have everyone follow in the same footprints and leave the area as soon as possible. (Note that having everyone follow in the same footsteps off established trails is the opposite of the general practice of spreading out when traveling cross-country—a practice that should be adhered to when crossing less fragile desert terrain).

Campsite selection and use

Practices are similar to the general practices. But particular responsibility is accepted when a pristine site is camped on, because any damage you cause will be there for a long time. With care, however, substantial impact can be avoided because there are many highly resistant environments in the desert (slickrock, dry washes, beaches, and even open ground between shrubs, if there is no cryptogamic crust). On all but the most resistant pristine sites, err on the side of caution by keeping group size down, keeping stays short and dispersing activities widely. Select a high impact site in popular areas and where you cannot be certain that you can leave a site with no evidence of your stay.

Avoid camping next to water unless you are in an area where water is abundant. This will minimize encounters with other parties that are drawn to the water source. More importantly, it will allow wary wildlife access to the water they need to survive and avoid harassment of the many animals that live in the rich environment the water supports. Camping close to water is probably more appealing in the desert than in any other environment, but this is where it is most critical to forego that luxury.

Fires and stoves

Practices are similar to the general practices. However, one quality of deserts makes fires particularly harmful there, while another provides opportunities to minimize fire impacts. The low productivity of deserts is reflected in slow replacement of wood burned in fires. Consequently, fires should be avoided except where there is an oft-replenished supply of driftwood (driftwood supplies are not replenished on many dam-controlled rivers) or where use levels are low. Even under these conditions fire should be minimized.

The prevalence of mineral soil makes it relatively simple to build a fire in such a way that you leave little trace when you leave. The very best sites are in the unconsolidated sands of a dry wash, where floods will eventually remove any evidence you do leave.

Sanitation

Practices are identical to those in the general practices. If you ignore the advice not to camp near scarce water sources, it is important to disperse widely and far from the water before depositing human waste in a cat-hole. Otherwise you may pollute the water supply and, in popular areas, risk either contracting or spreading diseases, due to excessive deposition of feces within a small area.

Waste disposal

Practices are identical to those in the general practices. If you ignore the advice not to camp near scarce water sources, extreme caution must be taken not to pollute water supplies with soap or other wastes.

2. HIGH ALTITUDE AND HIGH LATITUDE CONSERVATION PRACTICES

The common denominator of high altitude and high latitude environments is their low mean annual temperature and short, cool growing season. This confines growth to short and prostrate plants and limits productivity severely. Most plants adapt to these conditions by having most of their biomass underground. Consequently, there are many places where aboveground vegetation is sparse and mineral soil, rock and snow is abundant. Although annual productivity is low, places long-free from disturbance may be covered with luxuriant vegetation and may have well-developed soils rich in organic matter—vegetation and soil that has developed over centuries. Environmental heterogeneity, particularly in high altitude environments, is extremely high.

This greater heterogeneity at high altitudes is one of the primary differences between arctic and alpine environments. Alpine environments, depending upon local topography, can have longer and warmer growing seasons or they can be colder and less predictable than the arctic; there frequently is more late-lying snow. Another difference is the prevalence and importance of permafrost in many arctic landscapes.

The most unique characteristic of both of these environments is their low productivity, which makes recovery following disturbance extremely slow. Low resilience, along with a lack of firewood, makes these environments similar, as far as backcountry low-impact use is concerned, to deserts. Special caution must be taken to not disturb places that have not already been disturbed and fires should not be built except in emergencies.

Another similarity with deserts is the abundance of bare mineral soil, gravel and rock, particularly in alpine environments. This provides numerous resistant surfaces to use as routes when travelling cross-country or as pristine campsites. Also dense meadow turfs (tundra), with soil bound by the fibrous root masses of grasses and sedges, make quite resistant surfaces, as long as use levels are relatively low. Thus there are numerous means of minimizing impact as long as use levels are not high. Where use levels are high, however, it is important to stick to established trails and campsites, because resilience is so low.

A primary concern in arctic areas is to avoid heavy use of areas with permafrost with a high ice content. Loss of vegetation in such places will cause "thermokarst"—melting of the upper part of the permafrost, followed by subsidence and erosion of the soil. Loss of soil is catastrophic; we do not know how long it takes to replace an arctic soil but it must certainly be calculated in terms of thousands or tens of thousands of years. Try to confine travel to coarse-grained soils or bedrock and follow ridgetops or streambeds, avoiding wet areas with organic soils that are common in lower-lying areas.

Another feature to take advantage of are the many environments that experience frequent natural disturbance. Examples include large, braided glacial streams, caribou trails and slopes subject to solifluction. Any disturbance of such places will be removed in time by natural disturbances.

The "fragility" of high altitude and latitude environments, as with deserts, is more in how long scars last than in their ability to resist scarring. However, in some situations disturbance can be rapid and catastrophic, such as where lichen mats are destroyed or thermokarsting occurs. The keys to low-impact are (1) to either confine activities to resistant surfaces or, where this is not possible or use is heavy, to travel on existing trails and camp on high impact sites and (2) to minimize use of wood for fires.

Backcountry travel

Practices are not different from general practices, but it is particularly important to travel on established trails, except where use levels are low and you can be certain that you will leave no trace of your passage. Leaving no trace is not difficult where there is abundant bedrock, ice and snow. Meadow turfs and open tundra are also durable surfaces, although here you should spread out. In arctic tundra, the openness of vegetation and terrain makes it a simple matter to spread out and the prevalence of caribou trails provides numerous routes that have already been naturally disturbed. However, where soils are water-saturated or easily-displaced, particularly on steep slopes, or where vegetation is fragile, as in heath communities, you will leave evidence of your passage and, if enough other people follow in your footsteps, new and unwanted trails will develop. These are particularly unsightly at high altitudes and latitudes, where visibility is so high. Traveling in small groups and avoiding places where previous use is evident is important.

When following established trails, it is particularly important not to contribute to the development of braided or ever-widening trails. This is a common problem in these environments where trails cross mud holes or late-lying snowbanks, situations that can be widespread during early season (a good reason to avoid travel at this time). Stay in the trail tread and cross snowbanks directly or walk far from the trail, preferably on a hard surface.

Finally, because visibility is so great, it is particularly important to minimize your effect on other parties by avoiding brightly-colored equipment.

Campsite selection and use

As with backcountry travel, practices are not different from general practices, but the consequences of inappropriate behavior are particularly serious because impacts are so visually obtrusive and long-lasting. More responsibility must be accepted when not camping on a site that has already been highly impacted. This means selection of a resistant, undisturbed site, small groups, dispersal of activities, short stays, minimal disturbance of the site and camouflaging of any impact you do cause. The most resistant surfaces are on snow, ice, rock, gravel or unconsolidated mineral soil, such as along arctic rivers with large fluctuations in volume. If you must use vegetated surfaces, thick turfs of grass and sedge are quite resistant, while krummholz (prostrate trees near timberline), lichen-rich and heather communities are very fragile. Another recommended location is on small level areas below active solifluction lobes. Because these lobes are moving slowly downhill, they will eventually override the campsite and eliminate all traces of human disturbance. A common situation at high latitudes is to set up tents on dry tundra and a cooking area closeby in a gravelly stream bed. Impact should be minimal as long as care is taken to avoid the creation of trails between tent and cooking areas. This can be a particular problem where the area between tent and cooking areas is steep and wet. It is always important not to move rocks and stones—to create level campsites or build windscreens. Often vegetation can only get established in the protection of rocks, so their disturbance creates a permanent barren feature.

When using an established camp, it is particularly important to camp out-of-sight, due to the visual impact of other groups in the open landscape, and to avoid enlargement of the site and proliferation of user-built trails in the area.

Fires and stoves

Always use stoves at or above timberline, except in emergency situations, even where occasional patches of trees occur. Wood production is too low to support fires and the visual impact of fire scars is particularly pronounced in these open landscapes. The only exception is on streamside gravel bars in places where wood is relatively abundant and use levels are low.

Sanitation

Practices are similar to general practices, although this is the environment where surface disposal is most appropriate and group latrines are least appropriate. Soil and vegetation disturbance resulting from excavation of cat-holes will not recover rapidly and buried feces will decompose very slowly in the cold and sterile soil. These problems can be avoided if feces is deposited on the surface. Decomposition will be most rapid if the deposition site is in direct sunlight and exposure is increased by smearing the feces. However, surface disposal is only appropriate where there is no chance that other people will encounter it. This means it is important to seek out dispersed and isolated spots. It also provides an impetus to visit little-used places, when you are prepared to accept the responsibilities associated with off-trail hiking and camping.

In more popular places there is just no alternative to the use of cat-holes. Group latrines should be avoided at all costs, however, because such a concentration of waste simply will not decompose. It will be dug up by animals. This does not apply to existing latrines, which should always be used if available.

An option on glaciers is to make a latrine next to a deep crevasse, preferably one with relatively straight sides. With a shovel, feces can then be tossed to the bottom of the crevasse.

Waste disposal

Practices are similar to general practices, except that sump holes should never be excavated. Either use a naturally-occurring hole or disperse waste water widely.

3. CONSERVATION PRACTICES ON SNOW AND ICE

The presence of a thick mantle of snow or ice on the ground both offers unique opportunities for minimizing impact and presents unique challenges. The difficulties and hazards of cold place particular stresses on both wildlife and human visitors. Without special care this can result in serious impact that might not occur during warmer seasons or in less extreme environments.

A thick cover of snow shelters vegetation and soil from the normally inevitable impacts of trampling. Ice is also only ephemerally affected by trampling. Since trampling impacts are often the most serious unavoidable results of backcountry use, impacts caused by travel on snow or ice can quite easily be less pronounced than those at other seasons. However, as the snow mantle thins (either in early or late winter or in places where snow cover is less continuous), or as you leave the edge of an ice mass, the vulnerability of vegetation and soil increases to the point where they are much more easily disturbed than under snow-free summer conditions. This results primarily from the fragility of soils saturated with snow-melt waters. Such soils can become highly compacted and muddy and they are often easily displaced. Plants pressed into muddy soils have little chance of survival and plants growing in wet coarse soils are easily uprooted; plants can also be particularly vulnerable if they become brittle in fall or if they are just beginning to translocate nutrients from underground perennial tissues to aerial growing points in spring.

Probably the most important aspect of low-impact winter use is the need to minimize disturbance of wildlife. (This is less of a concern during travel on ice in other seasons.) Like humans, wildlife find winter a particularly challenging and stressful season. Unlike humans they do not have sleeping bags and tents to conserve heat and energy and they cannot bring their own food; they must scrounge for it under deep snow or in windswept areas. Finally, the large animals cannot travel on top of the snow, as humans do; they must plow through the snow, utilizing tremendous stores of energy when they must travel long distances. Given these problems, the most common winter strategy is to conserve energy by lowering activity levels—not moving rapidly or great distances unless absolutely necessary. Flight from recreationists and even an increased heartbeat associated with fright defeat this survival strategy. Energy consumption increases, so more food is required; but more energy is needed to seek out food and if food is scarce or there are large numbers of competing animals, some animals may not survive or the stress they undergo may reduce their reproductive capacity. Therefore it is critical in winter to stay far enough from wildlife to not induce flight or even cause fear.

Another unique characteristic of winter is that downed wood is covered by snow. Along with the difficulty of disguising fire remnants in winter, this makes fire a poor choice in winter.

Finally, proper disposal of human waste is extremely difficult, because it can be hard to dig down through the snow to the soil or to dig a cat-hole in frozen soil. This is probably the most difficult aspect of low-impact winter use. In popular areas for either summer or winter use, few acceptable solutions are available. Proper disposal on ice is even more problematic.

Backcountry travel

The primary concern with travel is minimizing impacts on wildlife. As long as the snow is deep, impact to vegetation and soil is minimal and except in a very few places use levels are so low that there need be little concern for other visitors. Consequently, many of the general guidelines can be relaxed. Bright clothes are more acceptable and can be desirable from a safety standpoint. Large groups are more acceptable and can be desirable from a wildlife impact perspective. Limited research suggests that frequent encounters with small groups are more disturbing than infrequent encounters with large groups. So it is probably best to keep groups close together and avoid dispersal of people or smaller groups in places that wildlife use for refuge. There is also little reason to be concerned about where you travel (other than to avoid wildlife disturbance). Cross-country and trail travel are equally acceptable and there is no need to worry about resistance of the ground. Perhaps the major

consideration, beyond wildlife, is that visiting places that are infrequently used during any season will make disposal of human waste and even having fires less problematic. In contrast to travel on solid ground, which is often quite fragile, dispersal of use and visitation of little-used places is always preferred on snow and ice.

On popular mountaineering routes, concern for minimizing your impact on other parties is required. Party sizes should be smaller and travel at less popular times is encouraged.

Campsite selection and use

As with the travel guidelines, the lack of trampling impact to soil and vegetation permits many guidelines to be relaxed. The most important considerations are to select a site where you will not disturb wildlife or pollute water supplies and where you can dispose of human waste properly. This can be accomplished by camping well away from trails and bodies of water—both those that are open in winter and those that will be running in spring or summer, as well as places that wildlife frequent.

There need be little concern for whether the site selected is pristine or highly impacted, for the resistance of the ground, for whether you concentrate or disperse tent sites and traffic routes, for size of the group or for length of stay—as long as wildlife is not disturbed and human waste can be disposed of properly.

There is some controversy about whether or not snow structures you build should be left standing. Although leaving them can provide comfort and even safety for you or others, this practice provides an unnecessary reminder that others have been here before and negates the principle of leaving pristine areas as they were found. Therefore, we suggest that such structures be removed unless there is a high likelihood that you will return on the same trip and you are in an area that is infrequently visited in winter.

Fires and stoves

There are several compelling reasons for not building fires in winter. Dead and downed wood that is dry is essentially non-existant, so the temptation will be to tear off lower branches or mutilate standing snags. Moreover, it is extremely difficult to properly dispose of the remains of a fire built in snow. Therefore, fires are not recommended except in an emergency. However, in remote areas that are seldom used during any season occasional small fires are acceptable, if care is taken to not disfigure trees when collecting firewood and some attempt is made to disperse charcoal and ash.

Sanitation

Practices are similar to those in the general practices, but it can be difficult to use the cathole technique properly. Given this difficulty, it is best to travel and camp in places that are seldom visited in summer. In such places, human waste can be deposited on the snow or ice in an out-of-the-way place, far from drainages. Decomposition will not occur after the feces is covered with snow and snowmelt waters will probably spread any pathogens, so it is critical that your disposal site is far from water (so it can break up and disperse) and in a place where human contact is unlikely. If you can dig a cathole in the ground, however, that is preferable.

In popular areas, the only solution is to try to emulate summer practices and make the effort to use catholes. If it is too difficult for everyone to dig their own personal holes, it may be necessary to construct a group latrine.

When travelling on glaciers, human waste can be deposited in crevasses. Although we do not know much about this practice, it is probable that feces will be ground up and pathogens will be dispersed before significant contamination occurs. As always, concentration of large quantities of waste in one area, particularly if it is frequently used by others, demands particular caution and should be avoided, if possible.

Kick snow over urination holes, unless in conditions (heavy current snowfall or no other winter users) where they will not be seen.

Waste disposal

Most practices are similar to the general practices. Waste water should be concentrated in one or a few holes and covered with snow when camp is broken. Extra care must be taken not to litter since it is so easy to lose items in the snow. Give special attention to plastic bags and wrappers and to candle wax. Candle wax should be caught in a cup and packed out.

4. COASTLINE CONSERVATION PRACTICES

The most unique and common characteristics of coastlines are the intertidal zone, the area between low and high tides that is strongly affected by incoming seas twice a day, and sporadic higher beach deposits that often extend inland for short distances, having been deposited by major storms or transported by winds. The intertidal zone can be either quite fragile (e.g. rocky tidepools that support an abundant flora and fauna) or extremely resitant (e.g. cobble, gravel or sand beaches). Intertidal and higher beach deposits are usually resistant because they consist almost entirely of unconsolidated mineral soil. Vegetation, organic matter and soil development are minimal; consequently there is little for human use to disturb. However, where vegetation has become established and, particularly, where embryonic dunes are forming, human impact can be significant. Loss of vegetation can cause accelerated wind erosion, greatly altering the morphology of the beach and, particularly, sand dunes.

In the intertidal zone, much of the evidence of human disturbance is removed by incoming tides twice a day and some inland areas are "cleansed" after major storms. Therefore, these resistant environments are also highly resilient. Most impacts that do occur are removed, depending upon their location, either daily or yearly. There are exceptions, however. Impacts beyond the zone disturbed by tides and major storms are similar to those that occur elsewhere. And, as mentioned earlier, certain environments within the intertidal zone and higher beaches are quite fragile and subject to long-term disturbance. Because much of the coast is particularly resistant and resilient, while some places are quite fragile, it is particularly important to concentrate activities on resistant beaches and particularly where tides or storms will cover evidence of human use.

The vast quantity of water in the ocean, along with the transporting effects of tides and currents, also provides a unique opportunity for dispersion and dilution of certain waste products that cannot be disposed of properly (other than to carry them out) in other environments. Most wastes that are not carried out are better deposited in the ocean than on land. However, because the abundant flora and fauna of tidepools are inundated by ocean waters, it is critical that concentrated dosages of pollutants are kept away from tidepools and camping areas.

Although the relative abundance of resistant and resilient substates and the ease of dispersing certain wastes in the ocean make coastlines relatively durable environments, certain problems are aggravated by the fact that use is concentrated along a narrow coastal strip. On popular routes, certain campsites are used over and over again and often by quite large groups. This contributes to localized problems with human waste disposal and trampling impacts beyond the beaches and intertidal zone, where vegetation and soils are better developed.

Generally, coastal zones should be the easiest environment for the recreationist to use responsibly. The overall keys to low-impact use of coastlines are to (1) concentrate activities on resistant substrates just above and below high tide lines, (2) avoid damage to tidepools and disturbance of wildlife, and (3) minimize sanitation problems by choosing less popular campsites, disposing of human waste in the ocean where possible and dispersing human waste widely on land where this is not possible.

Backcountry travel

Practices are the same as for the general practices, although some are particularly important here and some of the details are unique to coastlines. Because impacts to trails are minimal and campsite damage is limited by the resistance of available substrates, particular attention can be paid to minimizing

impact on other groups. Thus it is particularly worthwhile to travel during lightly used days and seasons and to select lightly used routes where this is possible.

The abundance of wildlife and edible foods should not lead to complacence. Wildlife disturbance should be avoided; give nesting birds and marine mammals a wide berth and take particular care not to damage tidepools. The eggs and young (up to 4-6 weeks) of brown pelican are vulnerable to predation, particularly by gulls and ravens, when your intrusion scares adults off nests. Gulls have even been known to follow humans and then eat eggs or young when adults flee. So be careful to avoid disturbing pelicans during nesting season. Disturbance of ospreys should also be minimized during nesting season. Edible foods, particularly shellfish, should not be overharvested. This may mean only harvesting in places that are not frequently visited. Finally, when spearfishing, take care to minimize the chance of maiming fish.

Campsite selection and use

Most practices are the same as for the general practices. The major difference is that use of relatively undisturbed sites is particularly appropriate on coastlines, even where use is heavy. This follows from the fact that sand, gravel and cobble beach substrates without soil development or vegetation are so abundant. These environments are little disturbed by use and evidence of use is usually removed quickly by high tides or large storms. They can be used repeatedly and for long periods, even by large groups, with little adverse impact.

Where resistant beach substrates are abundant there should be no need to choose a high impact site, regardless of how popular an area is. Merely select a resistant site on sand, gravel or cobbles for kitchen and sleeping areas. There is also no need to worry about either concentrating or dispersing tent sites or traffic routes as long as activities are confined to resistant substrates.

Where beach deposits are scarce or small, however, more care is needed. If beaches are small, confine as many activities as possible, including those associated with the kitchen, to the beach and set up sleeping areas further inland. When it is necessary to camp off the beach, follow the general guidelines for campsite selection and use and, in Baja California, the modifications for desert environments. There, dry washes are preferable locations to higher ground with more vegetation and better-developed soils and high impact sites should be used in popular areas. Avoid creating trail systems between tent and kitchen areas.

Fires and stoves

Practices are the same as for the general practices. As with campsite impacts, it is particularly easy to leave essentially no trace of fire impacts if fires are built on beaches below the high tide line. Such a fire is built on unconsolidated mineral soil where it will have little effect. Once all wood and charcoal is burned down to ash, ashes and rocks are thrown into the ocean, and excess firewood is scattered on land, the high tide will eliminate residual evidence of the fire.

If fires cannot be built on the beach, below the high tide, the need for a fire should be carefully evaluated. If necessary follow the general guidelines for fires and stoves and, in Baja California, the modifications for deserts.

The presence of driftwood makes firewood often—but not always—particularly abundant. Driftwood, particularly what has been milled or otherwise altered by humans, should be collected before using wood from further inland. Again, carefully consider the need for a fire if there is little driftwood or if use is sufficiently high to seriously deplete existing driftwood supplies.

Sanitation

The major difference from general practices is addition of the possibility of urinating and depositing feces directly in the ocean. It is a simple matter to urinate below the high tide line—away from the tide pool areas—where the ocean will quickly dilute the urine. Away from campsites, feces can be deposited on a rock and hurled into the ocean. Shells and flat rocks are abundant alternatives to toilet paper. An untried technique with considerable potential, particularly when using popular campsites, is to line an ammo box with paper (it must be biodegradable), have all party members deposit their feces in the lined ammo box and then deposit the paper and feces in the deep ocean on the next travel day. Where neither of these options are feasible follow the general guidelines for sanitation.

Waste disposal

The major difference from general practices is that certain wastes can be deposited directly in the ocean with little adverse effect. Fish viscera are generally a natural part of the ecosystem. Deposited below the high tide line—but away from camps—they will be scavenged by birds or eaten by fish. Away from popular campsites, it is probably less harmful to use biodegradable soaps directly in the ocean than to pour it onto the land—although this is a poor practice where large groups repeatedly use the same site or in areas of rich tidepool life. It is always best to minimize use of soaps and not deposit sizeable quantities in any single place.

Finally, in Baja California, cans can be deposited in the deep ocean after paper has been removed and the ends have been cut off. While such littering appears to run counter to the wildland ethic, the alternative in Baja is frequently that garbage is dumped alongside roads in the desert, an environment much less capable of degrading cans then the ocean deeps. This practice is not generally recommended in places where litter that is packed out is likely to end up in a legitimate garbage dump.

Cole, David N. 1989. Low-impact recreational practices for wilderness and backcountry. Gen. Tech. Rep. INT-265. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 131 p.

Describes low-impact practices that can contribute to minimizing problems resulting from recreational use of wilderness and backcountry. Each practice is described and information is provided on such subjects as rationale for the practice, importance, and costs to visitors. Practices that may be counter-productive are described, as are important research gaps.

KEYWORDS: no trace, minimum impact, recreation, visitor behavior

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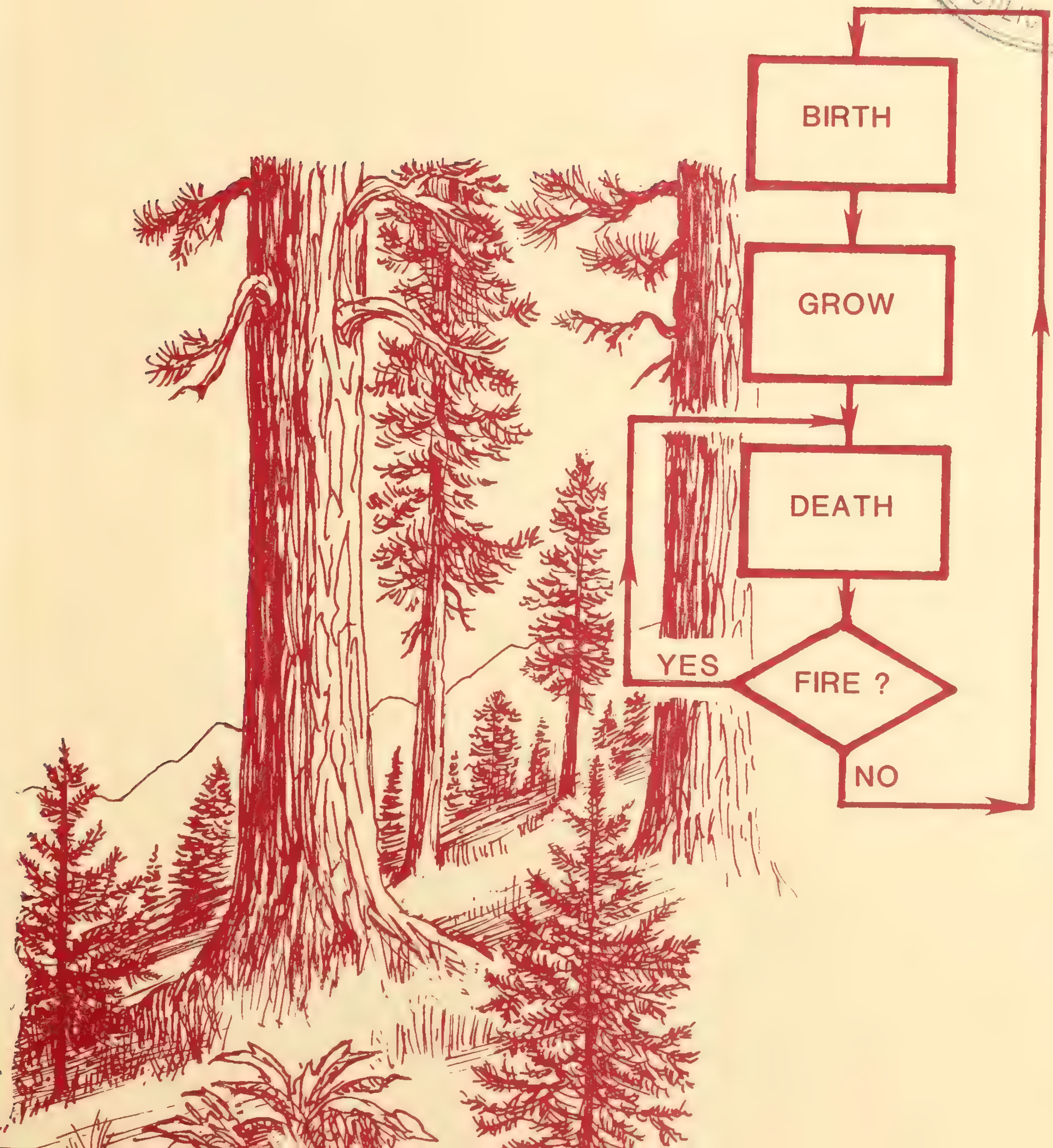
FIRESUM—An Ecological Process Model for Fire Succession in Western Conifer Forests

Robert E. Keane
Stephen F. Arno
James K. Brown



THE AUTHORS

ROBERT E. KEANE is a quantitative ecologist working under cooperative agreement with the Intermountain Research Station in Missoula, MT. He received his bachelor's degree from University of Maine in 1978 in forest engineering and his master's from University of Montana in 1985 in forestry. He has been working for the past 5 years developing ecological data analysis software for the Northern Region's Ecosystem Management Program and conducting computer modeling research with the Intermountain Research Station.

STEPHEN F. ARNO is a research forester in the Prescribed Fire and Fire Effects research work unit at the Intermountain Fire Sciences Laboratory, Intermountain Research Station, in Missoula, MT. He received a B.S. degree in forestry from Washington State University and master's and Ph.D. degrees from the University of Montana. He has studied various aspects of forest ecology since 1963.

JAMES K. BROWN is the leader of the Prescribed Fire and Fire Effects research work unit at the Intermountain Fire Sciences Laboratory in Missoula, MT. He received his bachelor's degree from the University of Minnesota in 1960, his master's degree from Yale University in 1961, and his Ph.D. degree from the University of Michigan in 1968, all in forestry. His past reseach has focused on fuel consumption, fire ecology of western forests, and development of prescribed burning guidelines.

RESEARCH SUMMARY

A successional process model has been developed to simulate long-term stand dynamics in forests of the Northern Rockies. The model can be used to evaluate fire effects differences for various fire regimes, including prescribed burning at different intervals, complete fire exclusion (fire suppression), and pre-1900 fire frequencies. The model, FIRESUM (a **FIRE SU**ccession **M**odel), simulates tree establishment, growth, and mortality, along with live and dead fuel accumulation, fire behavior, and fuel reduction on a 400-square-meter plot. The following influences on tree establishment and growth are included in the model: growing season warmth, water stress, light tolerance, and site quality. The model predicts basal area by species, duff and fuel accumulation, and fire intensities. All model algorithms are discussed, and corresponding parameters for several tree species are presented. The model is continually being tested and verified. Recent test results show FIRESUM underpredicts basal area by an average of 10 to 20 percent. A sensitivity analysis of FIRESUM showed that parameters associated with the growth algorithm are most critical. The model was designed so that it could be applied to different forest types with minimal modification of the computer code.

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Intermountain Research Station
324 25th Street
Ogden, UT 84401

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INTRODUCTION

The long-term effects on forest composition and structure of different fire management alternatives, such as complete suppression of all fires and prescribed fires of varying intervals and prescriptions, are often difficult to quantify. Although many researchers have studied successional communities arising after fire (Arno and others 1985; Kessell and Potter 1980; Steele and Geier-Hayes 1987; Stickney 1980; Means; 1981), investigations of the effects of successive fires—that is a "fire regime"—on vegetation are rare. The long time periods involved greatly complicate quantification of effects of successive fires based on field evidence. Computerized simulation models, however, offer an alternative means of comparing long-term effects of different fire regimes on forest vegetation. An additional benefit of developing such models is detection of areas where knowledge is deficient and future research is critically needed.

We developed a computer model, called FIRESUM (a **FIRE SU**ccession **M**odel), to simulate the effect of different fire regimes on tree composition, stand structure, and fuel loading in forests of the inland portion of the northwestern United States. Comparison of long-term fire effects predictions under different fire regimes could prove useful for developing fire management prescriptions to meet resource management objectives.

FIRESUM was created by extensively modifying the process model SILVA (Kercher and Axelrod 1981), which simulates forest succession involving fire in mixed conifer forests of the California Sierra Nevada. Parameters and algorithms within SILVA were revised, deleted, or added to reflect current knowledge of ecologic processes inherent in various types of forests. Currently, FIRESUM can be applied to ponderosa pine/Douglas-fir and whitebark pine/subalpine fir forests of the Inland Northwest and the Northern Rocky Mountains.

The purpose of this paper is to describe algorithms and routines used in FIRESUM along with related modeling assumptions. The parameters used to quantify each algorithm are also discussed.

THE MODEL

Model Description

FIRESUM is a deterministic model containing stochastic properties. Tree growth, woody fuel accumulation, and litterfall are simulated deterministically, whereas tree establishment and mortality are stochastic algorithms. The model simulates all processes on an individual tree level in a 400-square-meter area called the simulation plot. Because the particular combination of stochastic events occurring within a given FIRESUM simulation represent only one case among the set of many possible simulation outcomes, the model repeats simulations many times to obtain an average of simulated results.

FIRESUM is a gap-replacement model (Shugart and West 1980) following the approach used for JABOWA (Botkin and others 1972) in which individual trees are grown deterministically using an annual time step, difference equation. Tree growth is affected by several site factors, including available light, water stress, and growing season warmth. Tree establishment and mortality are modeled stochastically using Monte Carlo techniques. Fuel loadings are calculated yearly. Fires are introduced at various intervals, and effects of each fire are simulated by reduction of litter, duff, and down woody fuels; and by tree mortality and postfire tree regeneration and growth.

FIRESUM was programmed in the FORTRAN 77 language and contains over 2000 lines of code, with 43 subroutines and a main driver (appendix A). A generalized flow chart for FIRESUM execution is presented in figure 1. FIRESUM execution starts with tree and site parameters read into the program from external data files (TREE.DAT and SITE.DAT as shown in appendixes B and C) in subroutines TREE and SITE.DAT. External files allow efficient modification of parameters and facilitate the execution of simultaneous runs. The tree parameter file (appendix B) consists of numbers describing each tree species in terms of the model's algorithms. For example, the maximum height of each tree species used in growth algorithm of FIRESUM (H_m in appendix B) is represented in the tree parameter file. The site file (appendix C) contains parameters that describe the simulation site. Initial tree data for a sample plot are read from data file CONTRL.DAT (appendix D) into subroutine CONTRL and then these input trees are distributed on the plot in DIST. These data represent the simulation stand at the start of simulation. Parameters used to summarize site conditions are read from subroutine SITE.DAT and used to compute growth reduction factors in CALC and SITE. Frequency of cone crops and fire years are computed in CYCLES and RINGS, repectively. Establishment of new trees is done in BIRTH, trees are then grown in subroutine GROW and subject to mortality in KILL, thereby completing a normal tree life cycle.

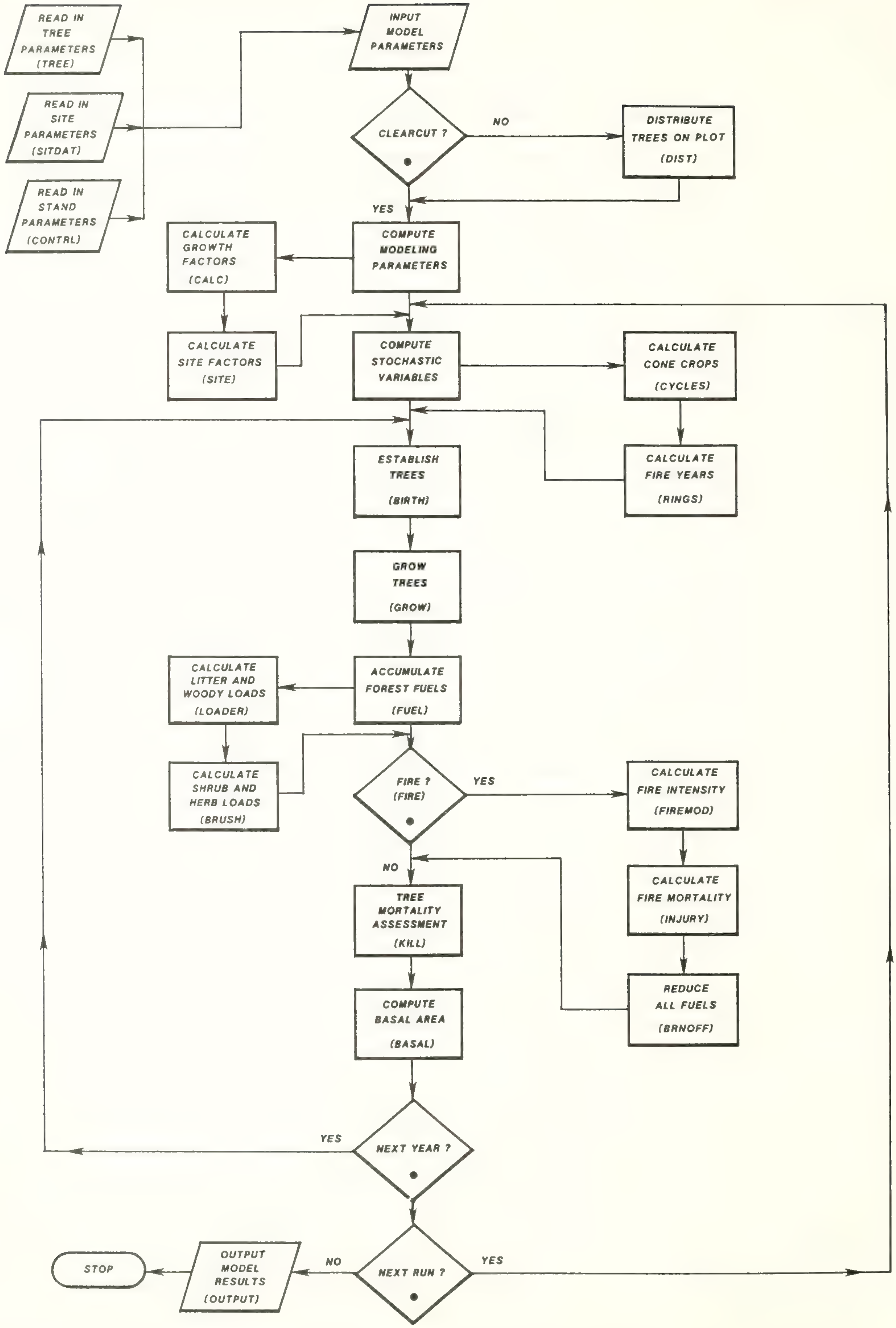


Figure 1—An instructional guide to program logic for the simulation process model FIRESUM. Program subroutines are noted in parentheses.

Fuel loadings are annually estimated in FUEL, LOADER, and BRUSH, and are passed to subroutine FIRE when a fire is initiated. Fire intensity is calculated in FIREMOD from these fuel loading predictions. Subsequent tree mortality from fire is estimated in INJURY using function RISK. Fuel reduction is performed in subroutine BRNOFF and the new loadings are passed back to FUEL. BASAL stores a running average annual basal area by species, which is then passed to subroutine OUTPUT at program termination. OUTPUT prints final results to external files.

Several subroutines not shown in figure 1 are also used in model execution. Subroutine SNAG estimates woody fuel contributed by recently dead trees and adds that amount to the fuel bed. FOLIAGE computes the leaf area of each tree on the simulation plot. Subroutines BEETLE and RUST are used to compute mortality caused by the mountain pine beetle and white pine blister rust. Crown fires are modeled in subroutine CROWN, which predicts when a ground or surface fire becomes hot enough to ignite tree crowns. This submodel is in the developmental stage and needs additional testing before implementation into FIRESUM. Subroutine RANDX is the random number generator. The growth reduction factor for water stress is computed in WRSTRS. The degree of shading based on leaf area is computed in SHADE, and the flame length is computed in FLTEMP.

The following are detailed descriptions of major simulation algorithms in FIRESUM. Values for parameters in these algorithms are shown in table 1.

Table 1—A summary table of parameter values for all species currently implemented in FIRESUM

Parameter	Tree species[2]									
symbol[1] (units)	PIPO	ABGR	PSME	PICO	LAOC	ABLA	PIEN	PIAL	PICO	LALY
Hm (cm)	6,562.5	5,333.7	5,715.0	4,115.0	6,857.5	4,175.5	5,456.0	3,657.0	4,115.0	3,048.0
Dm (cm)	250.5	139.4	208.8	110.0	250.0	126.7	234.4	182.0	110.0	168.0
AGEMAX (years)	450.0	275.0	350.0	220.0	450.0	180.0	320.0	1,000.0	350.0	800.0
DMIN (deg-days)	2,249.9	2,496.6	1,810.4	1,215.3	1,817.4	801.8	801.4	800.0	1,500.0	800.0
DOPT (deg-days)	4,010.0	4,200.0	4,200.0	4,200.0	4,200.0	3,800.0	3,800.0	3,000.0	3,000.0	3,000.0
DMAX (deg-days)	8,608.0	7,194.0	7,194.0	7,194.0	7,194.0	6,200.0	6,200.0	5,200.0	6,500.0	5,200.0
Shade tolerance[3]	I	T	M	I	I	T	M	M	I	I
SV (cm^2/cm^2)	57.6	72.9	69.1	64.7	184.0	70.0	54.2	57.6	64.7	184.0
PLA (m/m)	3.54	2.04	2.85	3.54	3.54	2.04	2.04	3.54	3.54	3.54
WSO (proportion)	.25	.47	.32	.38	.38	.65	.65	.33	.40	.75
Pc (probability)	.395	.333	.446	.318	.438	.333	.167	N/A	.318	.368
hc (years)	2.0	2.0	1.0	2.0	2.0	2.0	3.0	1.0	2.0	1.0
BC (proportion)	.070	.033	.065	.014	.069	.015	.022	.015	.014	.031
DKF (proportion)	.0575	.0339	.0339	.0460	.1310	.0339	.0339	.057	.044	.201
DKL (proportion)	.1116	.0667	.1167	.1186	.2000	.0667	.0667	.112	.112	.200
LTD (proportion)	.5500	.6500	.6500	.6600	.8500	.6500	.6500	.550	.660	.650
DKD (proportion)	.2280	.2210	.2210	.2210	.2210	.2210	.2210	.221	.221	.321
AINC (centimeters)	.012	.005	.007	.015	.016	.008	.008	.006	.016	.007
Lc (percent)	40.0	80.0	80.0	40.0	40.0	80.0	80.0	50.0	40.0	45.0
NYR (years)	4.0	7.0	5.0	3.0	1.0	7.0	6.0	7.0	3.0	1.0

[1]

Hm	=	Maximum attainable height	Pc	=	Probability of good cone crop
Dm	=	Maximum attainable diameter	hc	=	Years blocked after good cone crop
Agemax	=	Maximum attainable age	BC	=	Bark thickness conversion factor
DMIN	=	Minimum number degree-days	DKF	=	Decomposition loss from needlefall
DOPT	=	Optimum number of degree-days	DKL	=	Decomposition loss from litter
DMAX	=	Maximum number of degree-days	LTD	=	Decomposition loss from litter to duff
Shade tolerance	=	Shade tolerance class	DKD	=	Decomposition loss from duff
SV	=	Surface to volume ratio of foliage	AWC	=	Minimum diameter growth for mortality
PLA	=	Projected leaf area conversion factor	Lc	=	Live crown ratio
WSO	=	Minimum AET:PET ratio	NYR	=	Years needles remain on tree

[2]Species codes are: PIPO = ponderosa pine, ABGR = grand fir, PSME = Douglas-fir, LAOC = western larch, ABLA = subalpine fir, PIEN = Engelmann spruce, PIAL = whitebark pine, PICO = lodgepole pine, LALY = subalpine larch.

[3]Shade tolerance categories are I-shade intolerant, M-moderately shade tolerant, and T-shade tolerant.

Tree Growth (Subroutine GROW)

Growth is modeled by an annual increase in tree diameter measured at breast height (d.b.h.) [1.37 meters above ground line] (Botkin and others 1972). Diameter increment growth (dD/dt) is calculated from the time step equation:

$$\frac{dD}{dt} = \frac{G\,D\,[1 - (DH)/(D_m H_m)]}{274 + 3b_2 D - 4b_3 D^2}\,[rAL\; rN\; rW\; rDEGD] \quad (1)$$

where D is the diameter (d.b.h. in centimeters) and H is the height of the tree (centimeters), D_m and H_m are maximum attainable d.b.h. and height (centimeters) for the tree species in the Northern Rocky Mountain region. Values for D_m and H_m (table 1) are taken from Patterson and others (1985), Fowells (1965), Pando (1973), Pfister and others (1977), Hunt (1986), and other studies of old-growth forests. Tree height (H) is computed from:

$$H = 137 + b_2 D - b_3 D^2 \quad (2)$$

where b_2 and b_3 are species-dependent constants. Constants G, b_2, and b_3 are estimated using equations 3 and 5 in Botkin and others (1972), which have D_m, H_m, and maximum attainable age (AGEMAX in years) as independent variables.

The remaining variables in the equation are growth reduction factors (values between 0.0 and 1.2) that represent the total effect of surrounding environment on tree growth. These factors are modeled as tree growth response to available light (rAL), nutrient supply (rN), water relations (rW), and temperature regime ($rDEGD$). Optimal growth is only possible when all factors equal 1.0.

Available light (AL) for an individual tree is calculated according to Beer's Law (Kercher and Axelrod 1982) using the equation:

$$AL = AL_o e^{(-k_j\ \Sigma LAI)} \quad (3)$$

where ΣLAI is the sum of leaf area indexes for all trees taller than the tree under consideration and AL_o is available light at full sunlight (standardized to 1.0). Variable k_j is the extinction coefficient per meter for canopy type j.

Because forest canopy characteristics differ by tree composition, that is forest community, it was necessary to stratify extinction coefficient (k) (and many other simulation parameters mentioned later in this paper) by a classification of fire groups (Davis and others 1980) synthesized from the Montana habitat types of Pfister and others (1977). In their classification, habitat types were grouped into similar categories based on vegetation composition, tree ecology and fire histories (table 2). Canopy extinction coefficients by fire group are presented in table 3.

Because utilization of available light by a tree depends on degree of shade tolerance for that species, light response equations were stratified by shade tolerance class (shade intolerant, moderately shade tolerant, and shade tolerant as shown in table 1). These equations, from Botkin and others (1972), are

$$\text{Shade tolerant:}\quad rAL = 1 - e^{[-4.64\,(AL - 0.05)]} \quad (4)$$

$$\text{Shade intolerant:}\quad rAL = 2.24\,[1 - e^{[-1.136\,(AL - 0.08)]}] \quad (5)$$

where rAL is a dimensionless number between zero and 1.0 (1.2 for shade intolerant species), and AL expresses available light (also dimensionless). Shade-tolerant species are able to attain higher growth rates in heavily shaded conditions (fig. 2). But light saturation for tolerant species occurs at a much lower level of photosynthetic activity than for the shade intolerants. Although three tolerance classes are recognized in FIRESUM, the tolerant equation (4) includes species that are tolerant and moderately tolerant of shade.

Leaf area was difficult to calculate due to the absence of leaf area equations for Inland Northwest tree species. In FIRESUM we estimated leaf area (LA in square centimeters) from:

$$LA = \frac{[(CW*PFOL)/CD] * SV_i}{PLA_i} \quad (6)$$

where CW is crown weight in grams, $PFOL$ is proportion of crown that is foliar weight, CD is needle density in grams per cubic centimeter (assumed to be 0.5 for all species based on the authors' unpublished data), SV_i is

Table 2—Fire groups implemented in FIRESUM. Tree species prevalent in the ponderosa pine/Douglas-fir forests are capable of attaining dominance in any of these fire groups

Number	Fire group name[1]	Predominant overstory	Fire frequency
1	Warm, dry ponderosa pine	Pure ponderosa pine	3-8 year intervals
2	** Grand fir	Larch, Douglas-fir, ponderosa pine, grand fir	20-200 years
3	** Warm, dry Douglas-fir	Ponderosa pine, Douglas-fir	5-20+ years
4	Cool, dry Douglas-fir	Douglas-fir	35-40 years
5	** Moist Douglas-fir	Douglas-fir, lodgepole pine, ponderosa pine	around 40 years
6	Cool habitat types	Lodgepole pine	100-500 years
7	Dry, lower subalpine types	Douglas-fir, lodgepole pine, spruce	50-130 years

[1] Fire groups are from Davis and others (1980).

** Only these fire groups have ponderosa pine/Douglas-fir ecosystems. The other groups are included in FIRESUM for future research. All fire groups contain the seven species implemented in FIRESUM.

Table 3—FIRESUM parameter values stratified by fire group. Descriptions of the fire groups are provided in Table 2 (Davis and others 1980)

Parameter symbol[1]	Fire group number 1	2	3	4	5	6	7
k	0.426	0.525	0.426	0.426	0.426	0.426	0.525
BARMAX	.0071	.0149	.0074	.0091	.0107	.0083	.0111
SPM	1.0	6.0	2.0	4.0	3.0	5.0	5.0
PRO	.990	.717	.668	.768	.768	.985	.852
LBULK	15.8	41.6	21.9	25.3	36.0	43.3	38.1
DBULK	76.9	45.8	76.9	110.6	110.6	139.5	142.7

[1]Parameter descriptions:
k = Extinction coefficient (dimensionless)
BARMAX = Maximum attainable basal area (m^2/m^2)
SPM = Maximum seedling density (seedlings/m^2)
PRO = Dead shrubby fuel in shrub biomass (proportion)
LBULK = Bulk density of litter (kg/m^3)
DBULK = Bulk density of duff (kg/m^3)

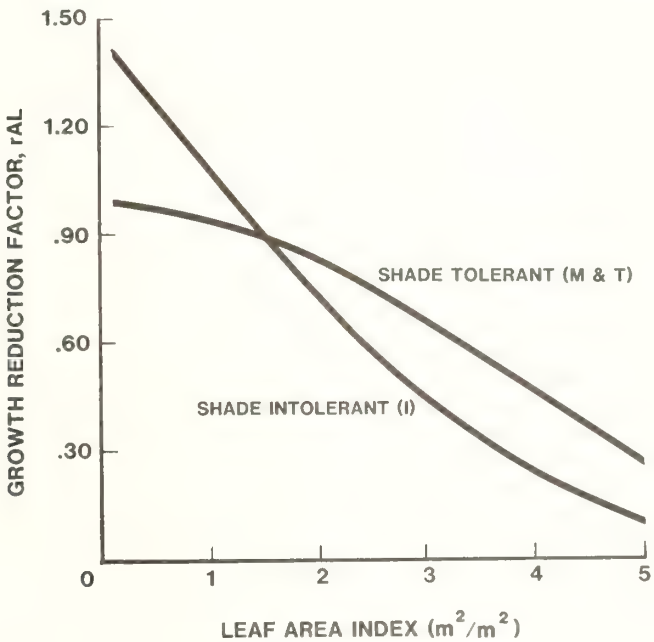


Figure 2—Relationship of the growth reduction factor for shading to leaf area index (equations 4, 5). This range of leaf area indexes is commonly found in ponderosa pine/Douglas-fir forests of the Inland Northwest. Shade tolerant categories *M* (moderately shade tolerant) and *T* (shade tolerant) are represented by the same function. Shade intolerant species (*I*) have a different function.

needle surface-to-volume ratio for species i (values are from Lopushinsky [1970], Brown [1970], and Minore [1979]), and PLA_i is a conversion factor to estimate projected leaf area from all-sided leaf area for species i (values calculated from Kaufmann and others [1982], Smith [1972], and unpublished data). Crown weight and proportion foliar weight are estimated from regression equations (Brown 1976, 1978; Moeur 1981) that use d.b.h. as the independent variable. All other variables are constants (table 1).

The effect of resource availability (tree crowding) on tree growth was indirectly modeled as a function of stand basal area with the equation:

$$rN = 1 - (BAR/BARMAX_j) \qquad (7)$$

where BAR is basal area (square meters) of simulation stand and $BARMAX_j$ is maximum attainable basal area (square meters) for stands in fire group j. Values for $BARMAX_j$ (table 3) are estimated from Pfister and others (1977) and Arno and others (1985). The factor rN goes to zero as BAR approaches $BARMAX_j$ (fig. 3).

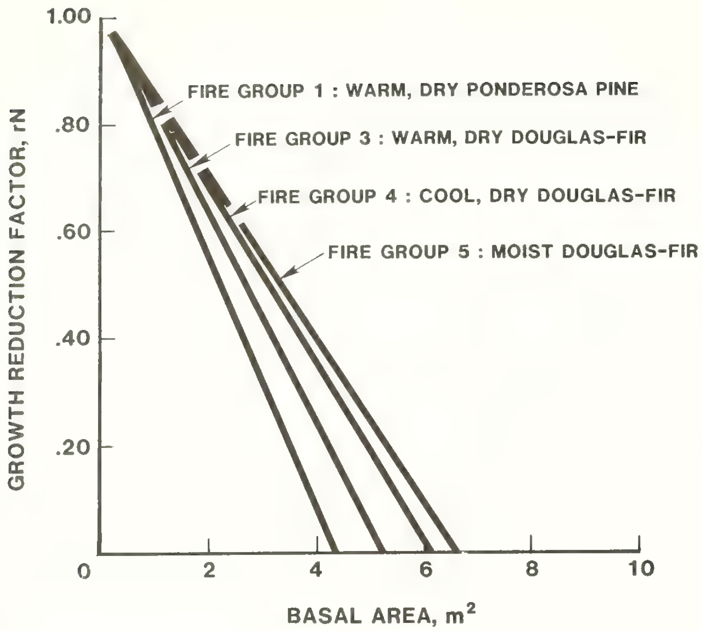


Figure 3—Growth reduction factor (*rN*) relationship to plot basal area in four fire groups.

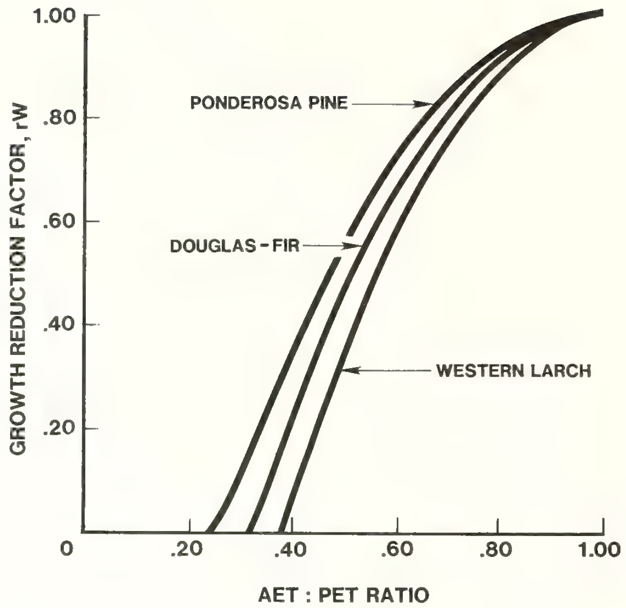


Figure 4—Relationship of the growth reduction factor *rW* to the simulation plot's actual to potential evapotranspiration ratio (AET:PET).

Modeling growth response to water stress (rW) in FIRESUM is taken from Reed (1980) and Reed and Clark (1979) where the ratio of actual to potential evapotranspiration (AET:PET) is the driving variable. This ratio indicates the relative aridity of the simulation climate. The water response (rW) equation is:

$$rW = 1 - [(1 - APR)/(1 - WSO_i)]^2 \qquad (8)$$

where APR is the annual AET:PET ratio for the site and WSO is the lower limit of tolerance in APR for species i. This parabolic function (fig. 4) reaches maximum when APR equals 1.0, which assumes growth is not inhibited when annual AET exceeds annual PET. Values of WSO_i for each species were calculated from weather data collected at or near near the edge of species i's natural distribution where water becomes the limiting factor (Little 1971). Actual evapotranspiration is calculated using the water balance equations presented in Kercher and Axelrod (1981), which use monthly precipitation (*BASEP*), soil water-holding capacity (*TEXT*), soil depth (*TILL*), and a runoff constant (*EXCESS*) as variables (values shown in appendix C). Potential evapotranspiration is calculated from the Thornthwaite and Mather (1957) equations.

Climatic influence on diameter growth was modeled as a function of temperature expressed as growing degree-days (Botkin and others 1972; Shugart and Nobel 1981). The parabolic equation taken from Reed and Clark (1979) is given as

when $DMIN_i < DEGD < DMAX_i$:

$$rDEGD = \frac{[(DEGD - DMIN_i)\,(DMAX_i - DEGD)]^V}{[(DOPT_i - DMIN_i)\,(DMAX_i - DOPT_i)]^V} \qquad (9)$$

where $V = (DMAX_i - DOPT_i)/(DOPT_i - DMIN_i)$

when $DEGD < DMIN_i$ or $DEGD > DMAX_i$:

$$rDEGD = 0.0 \qquad (10)$$

where $rDEGD$ is a number between 0 and 1.0, $DEGD$ is number of degree-days calculated from weather data submitted as input for a simulation run; $DMIN_i$ and $DMAX_i$ are the maximum and minimum degree-days defining the geographic range of species i; and $DOPT_i$ is number of degree-days for optimum growth of species i.

Figure 5 illustrates the ability of Douglas-fir to grow in colder environments (lower number of degree-days) as compared with ponderosa pine. Note the value $rDEGD$ equals 1.0 at $DOPT_i$. Growing degree-days are calculated using equation 9 in Botkin and others (1972). This equation employs a base temperature of 4 °C to define growing season and uses mean monthly temperatures for January and July as minimum and maximum yearly temperatures. $DMAX_i$ and $DMIN_i$ were estimated from weather data collected at extremes of species i's geographical distribution in the Inland Northwest (Shugart 1984). $DOPT_i$ was calculated from weather data at stations that were at or near areas where site index values for species i were maximum. Additional information from Alexander and others (1984), Dale and Hemstrom (1984), Fowells (1965), Hellmers and others (1970), and Little (1971) was used to further quantify these three parameters (table 1).

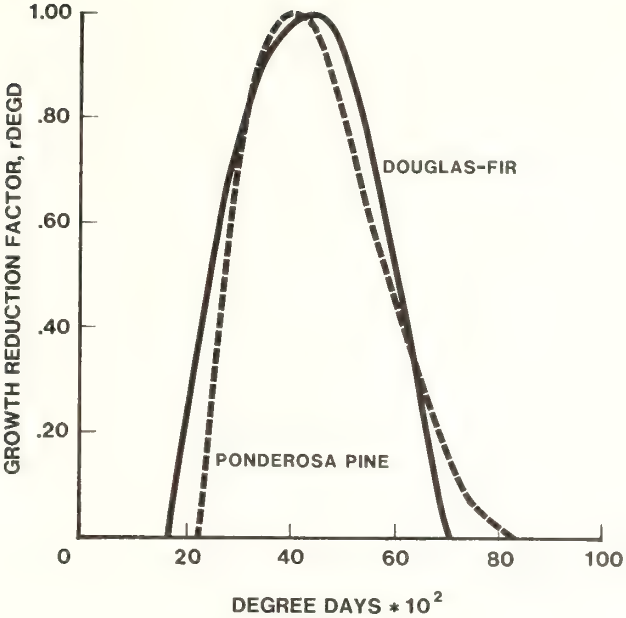


Figure 5—The relationship of degree-days for the simulation plot to the growth reduction factor representing growing season warmth and its effect on tree growth (*rDEGD*).

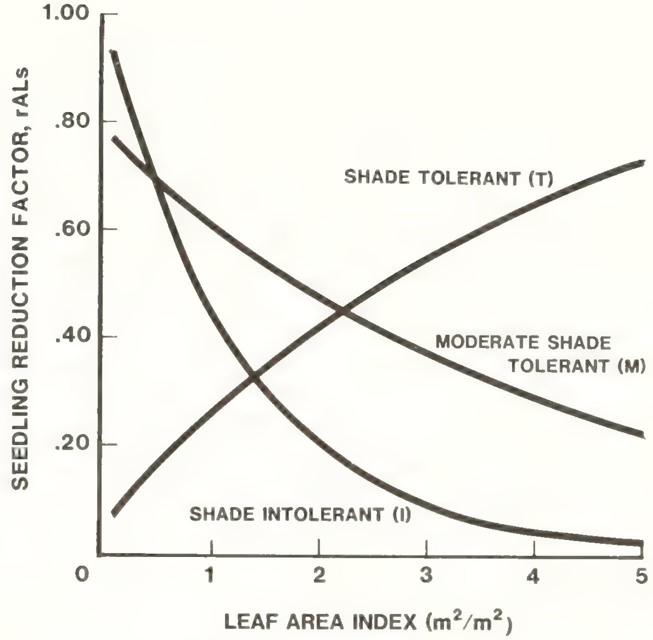


Figure 6—Effects of shading (leaf area index) on the seedling reduction factor *rALs* for three shade tolerance categories.

Tree Regeneration (Subroutine BIRTH)

Trees were established on the simulation plot if two criteria were met. First, simulated growing degree-days (*DEGD*) had to exceed $DMIN_i$ for the species under consideration (Knapp and Smith 1982; Shugart 1984; Weinstein and others 1982); and second, the threshold AET:PET ratio (defined earlier as *APR* in subroutine GROW) had to be greater than WSO_i (Brix 1979; Kercher and Axelrod 1984; Lopushinsky and Klock 1974). If the above criteria were true, then size of cone crop was evaluated.

Each year a species can have a good or poor cone crop, but trees are established only in good seed years. The Monte Carlo method discussed in Kercher and Axelrod (1984) was used to determine good cone crop years. In this stochastic method, p_c is the probabilty of a good cone crop. Each year a random number is generated and, if it is less than p_c, a good cone crop is simulated. But this process is blocked for a number of years after a good cone crop (Kercher and Axelrod 1981). The number of blocked years (h_c–1) is based on the assumption that trees must store sufficient energy reserves before generating another good cone crop. Good seed years are determined at the beginning of each simulation run and remain constant for each replicate run within a simulation. Values for parameters p_c and h_c (table 1) are from Boe (1954), Eis and Craigdallie (1983), Lotan and Perry (1983), Shearer (1985), and Shearer and Schmidt (1970).

The number of trees established on the simulation plot is calculated from the equation:

$$FNJ_i = SPM_j * PTREE_i * PSUR_i * rAL_s * rSRF_i \quad (11)$$

where FNJ_i is the number of seedlings established for species *i*, SPM_j is the maximum number of seedlings (includes all species) that can become established on 1.0 m² for fire group *j*, $PTREE_i$ is proportion of seed trees of species *i*, $PSUR_i$ is the probability of seedling survival considering the duff depth, rAL_s is a reduction factor accounting for effects of limited light on seedling establishment, and *rSRF* is a reduction factor that models the effect of distance of seed source on tree establishment.

The factor rAL_s ranges from 0 to 1.0, depending on three levels of shade tolerance. The set of equations for calculating rAL_s are:

Shade intolerant: $$rAL_s = e^{(-0.8*LAI)} \quad (12)$$

Moderate shade tolerant: $$rAL_s = e^{(-0.25*LAI - 1.0)} \quad (13)$$

Shade tolerant: $$rAL_s = 1 - e^{(-0.25*LAI - 0.2)} \quad (14)$$

where *LAI* is plot leaf area index (square meters of leaf area per square meter of plot area). The coefficients were derived by the authors, based on unpublished data about the dynamics of seedling establishment. Shade-tolerant species are able to establish the most seedlings at low light levels (fig. 6) (Grime and Jeffery 1965).

Values for SPM_j (table 3) were taken from Alexander (1984), Arno and others (1985), Knapp and Smith (1982), Pfister and Shearer (1977), Schimdt and others (1976), Shearer (1974), Shearer (1975), and Shearer (1985). Seed trees were defined as any tree greater than 10 cm d.b.h. or having an age greater than some minimum threshold (variable *YSC*, values shown in appendix B). This assumes only trees meeting these criterion are able to

produce appreciable quantities of seed. The variable $PTREE_i$ roughly estimates a species contribution to the seedbank; it is calculated by dividing the number of seed trees for species i by the total number seed trees. To account for off-site seed dispersion, tree species not represented on the plot were assigned a value of 0.05 for $PTREE_i$.

$PSUR_i$ was calculated using regression equations developed from a study on litter and duff depth reduction in north Idaho (Boyce 1985). The independent variable in these equations is depth of litter and duff in centimeters (DEPTH). These equations are:

Ponderosa pine:
$$PSUR = 1.0 - 0.164 * DEPTH \qquad R^2 = 0.94 \tag{15}$$

Grand fir:
$$PSUR = 1.0 - 0.149 * DEPTH \qquad R^2 = 0.90 \tag{16}$$

Douglas-fir:
$$PSUR = 1.0 - 0.160 * DEPTH \qquad R^2 = 0.99 \tag{17}$$

Lodgepole pine:
$$PSUR = 1.0 - 0.161 * DEPTH \qquad R^2 = 0.93 \tag{18}$$

Western larch:
$$PSUR = 1.0 - 0.177 * DEPTH \qquad R^2 = 0.99 \tag{19}$$

In the absence of specific data for subalpine fir and Engelmann spruce, the grand fir equation was used to represent $PSUR$ for those species. Negative values for $PSUR$ were equated to zero.

The distance the simulation plot is from seed sources directly influences the number of trees established. Factor $rSRF$ attempts to simulate this relationship. Reduction equations are of the form:

$$Y_i = \frac{e^{(a+bX_i)}}{e^a} \tag{20}$$

where Y_i is the $rSRF$ for species i with values between 0 and 1, X_i is the distance from species i's seed source, which is input into FIRESUM (value $DIST$ in appendix D); and a and b are species-derived constants based on data provided by McCauley and others (1985). These values (variable $DISEQU(1,i)$ for a, variable $DISEQU(2,i)$ for coefficient b) are shown in appendix B.

All new trees are established as saplings of 1.0 cm diameter at breast height (d.b.h.) and 1.37 m tall. These new trees are added to the simulation after a lag period of 25 to 50 years, depending on the site (value LAG in appendix B).

The absence of seed trees for a species on the plot presents a special case in FIRESUM. Distances to seed source from simulation plot by species are input into the model. The factor $rSRF$ and the number of seed trees are computed annually for each species. But the value of $rSRF$ only enters into the seedling equation(s) when all seed trees of that species are eliminated from the simulation plot, because of beetle epidemic or successional replacement, for example. It is assumed in FIRESUM that the seed source of eliminated species composes 5 percent of the total seed crop trees outside the simulation plot for all tree species but whitebark pine. If all trees are killed on the plot, such as after a crown fire, the seed source stand is assumed to be identical to the preburn simulation stand.

Whitebark pine regeneration is computed in subroutine PINALB (appendix A), which models the effects of seed crop, Clark's nutcrackers, and light on whitebark regeneration (Keane and others 1989b). This routine is very different from that used for other species and shows how FIRESUM can be modified to simulate life cycles for any tree species. A complete discussion on the whitebark pine regeneration algorithm is presented in Keane and others (1989b).

Tree Mortality (Subroutine KILL)

Four types of tree mortality—random, stress, fire, and insects and disease—are recognized in FIRESUM and are modeled as stochastic functions. "Random mortality" is the chance of death, from endemic insect attack, windthrow, or other local perturbations that a tree experiences throughout its lifetime. The probability of random mortality (P_r) is calculated by the equation:

$$P_r = 4/AGEMAX_i \tag{21}$$

where $AGEMAX_i$ is the maximum attainable age for species i. It was assumed that only 2 percent of the trees survive to $AGEMAX_i$ to derive equation 21 (Botkin and others 1972). Analysis of stand data from Montana, Idaho, and eastern Oregon (Arno and others 1985; Keen 1940; Seidel 1975) suggests that 2 percent is reasonable.

"Stress mortality" is tree death resulting from severe stress over periods of 2 to 50 years. Stress mortality can be caused by water scarcity, insufficient light, or tree crowding (Kercher and Axelrod 1984, Shugart and Noble 1981). The probability of stress mortality (P_s) is a function of growth increment. If a tree's annual growth increment ($DINC$) is less than a threshold value ($AINC$) for that species, the following equation is executed:

$$P_{s(n+1)} = P_{s(n)} + 0.2 - 0.2\,P_{s(n)} \tag{22}$$

where n is the number of stressful years.

A new P_s is calculated each year $DINC$ is less than $AINC$. P_s will eventually equal 0.997 after 30 years in this stressed condition. Values for $AINC$ were estimated by examining the cross-sections of numerous severely suppressed trees.

Mortality due to fire is modeled as a function of fire intensity. When a fire spreads through an area it kills trees by scorching foliage and killing bole cambium. The degree of crown scorch and cambial kill depends on fire intensity and duration. Ryan and Reinhardt (1988) developed an empirical mortality equation that implicitly accounts for both causes of fire death (fig. 7). The equation is:

$$P_{fk} = \frac{1}{1 + \mathrm{EXP}[-1.941+6.32(1-\mathrm{EXP}(BC_i D_k))+0.000535\, CK_k^{\,2}]} \tag{23}$$

where P_f is the probability of mortality from fire for tree k, BC_i is a bark conversion factor for species i, which multiplied by D_k (d.b.h. of tree k in centimeters) provides an estimate of bark thickness for tree k, and CK_k is percentage of scorched crown volume for tree k. Values for BC_i are taken from Faurot (1977), Lange (1971), Lynch (1959), Myers and Alexander (1972), and Ryan and Reinhardt (1988).

Assuming crown shape approximates a paraboloid (Peterson 1985; Ryan and Reinhardt 1988), scorched crown volume was estimated using:

$$CK_k = 100\,[B(2L-b) / L^2] \tag{24}$$

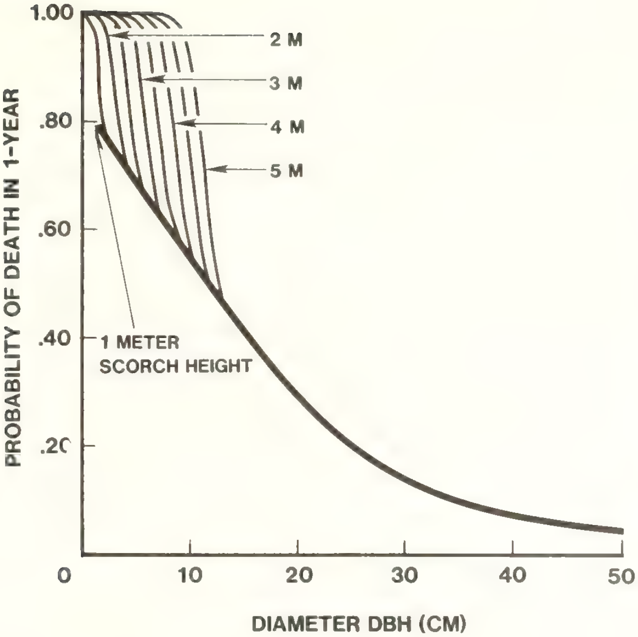


Figure 7—Mortality of ponderosa pine as related to tree diameter (d.b.h.) and crown scorch height. Taken from Ryan and Reinhardt (1988).

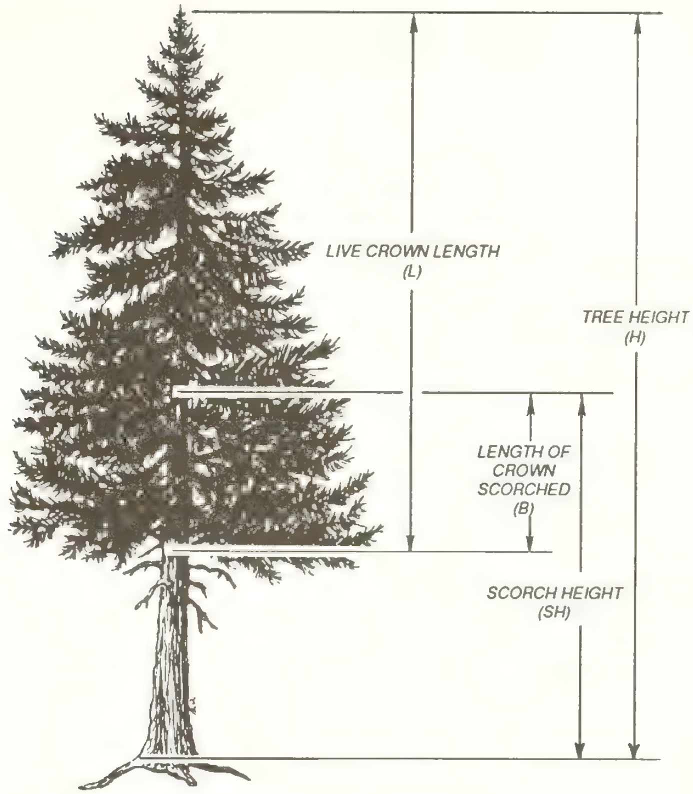


Figure 8—Diagram of important tree dimensions used in the calculation of percent crown scorched. This variable is used to compute tree mortality.

The dimensions B(length of scorched crown in centimeters) and L (length of crown in centimeters) are calculated from tree height and crown length (fig. 8). Tree height (H_k in centimeters) is calculated from the equation:

$$H_k = 137 + b_2 D_k - b_3 D_k^{\,2} \tag{25}$$

where b_2 and b_3 are the species-dependent constants described in the Tree Growth section. The length of crown (L) is the product of live crown ratio (L_c) and tree height. The dimension B is solved by the equation:

$$B = SH - [H - L] \tag{26}$$

where SH is scorch height. Scorch height in meters is calculated from an empirical expression developed by Van Wagner (1973):

$$SH = \frac{C_1 (FI)^{7/6}}{[C_2 (FI) + (C_3 (WIND)^3]^{1/2}\,(TKILL - T)} \tag{27}$$

where FI is fire intensity (kilowatts per meter of fireline), $WIND$ is wind speed (kilometers /hour) at midflame height, T is ambient temperature (degrees Celsius), and $TKILL$ is the lethal temperature for tree foliage (assumed as 60 °C). The constants C_1, C_2 and C_3 were derived empirically and are 0.742 m/°C, 0.0256 (kW/m)$^{4/3}$, and 0.278 h/km (kW/m)$^{7/9}$, respectively. Fire intensity is discussed later. Ambient temperature (T) was assumed to be 20 °C, a typical temperature for prescribed fire. Kercher and Axelrod (1984) found equation (26) to be very sensitive to windspeed at high fuel loadings and insensitive to windspeed at low loadings.

Although the mortality equation (23) includes a wide range of diameters and species, data for small diameter tree mortality were lacking. Because the majority of simulated trees are less than 10 cm d.b.h., additional validation of the equation with small diameter tree mortality is needed.

Insect and disease mortality is the fourth type of tree mortality represented in FIRESUM. Each insect and disease mortality algorithm was developed from empirical data using regression analysis. In the regression equations, probability of mortality (Y-variable) is computed from many types of independent variables (X-variables) including tree diameter, tree densities, proportion of trees infested, and some site variables. Each type of insect or disease is represented by regression equations for each species it may affect. Also, these equations are stratified by fire group. Currently, FIRESUM models mountain pine beetle-caused mortality on lodgepole pine and whitebark pine, and white pine blister rust-caused mortality on whitebark pine in whitebark pine/subalpine fir forests (Keane and others 1989b). Additional insect and disease mortality equations will be included as they are needed.

Each tree that dies, regardless of the cause of mortality, contributes a portion of its woody branchwood and all of its needles to the fuel bed. Weight of branchwood less than 3 inches in diameter for dead trees is calculated from equations by Brown (1978) and divided equally into the three smallest fuel components (discussed in the next section). It is assumed scorched foliage is not consumed by the fire and is added to the fuel bed, unless the fire was a crown fire. It is assumed all foliage is consumed by a crown fire. Needle weight is computed from equations presented in Brown (1978).

Fuel Accumulation (Subroutine FUEL)

Six dead and two live fuel components are recognized in FIRESUM (table 4). Loadings for these eight fuel components are computed annually, and if a fire is simulated, all fuel loadings are passed to subroutine FIRE, where they are used to estimate fire intensity. Accumulation algorithms are used to represent annual fuel increments for (1) dead woody fuel components, (2) litter and duff components, and (3) live and dead shrub and herbaceous components.

The 1-, 10-, and 100-hour timelag dead woody fuel components are updated each year using the following equations:

if $WOOD_{fy} < WOODMAX_{fj}$ then

$$WOOD_{fy+1} = WOOD_{fy} + WOODMAX_{fj} / WYR_{fj} \quad (28)$$

else if $WOOD_{fy} > WOODMAX_{fj}$ then

$$WOOD_{fy+1} = WOODMAX_{fj} \quad (29)$$

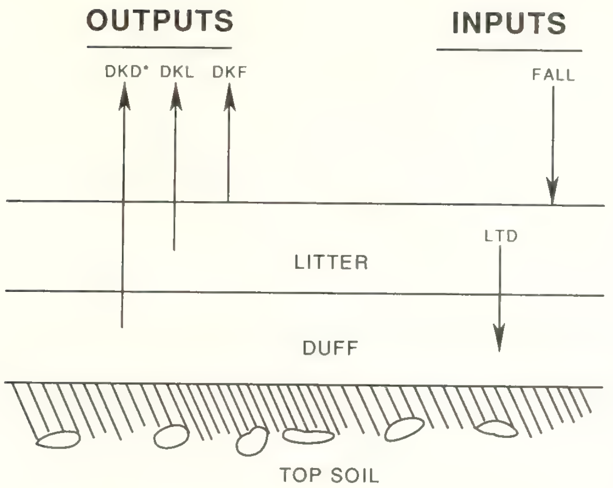
where $WOOD_{fy}$ is fuel loading (kilograms per square meter) for woody fuel component f at year y, $WOODMAX_{fj}$ is the maximum attainable fuel loading for component f in fire group j, and WYR_f is the number of years to reach $WOODMAX_f$ in an undisturbed forest for component f in fire group j. Parameter values (table 5) were taken from Bevins (1977), Brown and Bevins (1986), Brown and See (1981), Jeske and Bevins (1976), Mathews (1972), van Wagtendonk (1972). These equations operate under the assumption of constant accumulation and decomposition rates.

Table 4—Fuel components included in FIRESUM. Timelag woody branchwood categories are described in Fosberg (1970)

Number	Fuel component	Description
	Dead Fuel	
		Litter Fuel
1	Litter	Downed tree foliage, no duff material contributes to fire
		Downed Woody Branchwood
2	1-hour time lag	Twigs and branches 0 to 1/4 inch in diameter
3	10-hour time lag	Twigs and branches 1/4 to 1 inch in diameter
4	100-hour time lag	Twigs and branches 1 to 3 inches in diameter
		Shrub and Herbaceous Fuel
5	Shrub	Shrub stemwood 0 to 1 inch diameter
6	Herbaceous	Grass and forbs
	Live Fuel	
		Shrub and Herbaceous Fuel
7	Shrub	Foliage and small stemwood on live shrubs
8	Herbaceous	Grass and forbs living on forest floor

Table 5—Parameter values for woody fuel accumulation equations (28) and (29). WOODMAX is the maximum fuel loading and WYR is the time required to reach maximum fuel loading

	Fire group number						
Parameter symbol	1	2	3	4	5	6	7
			1-hour dead woody branchwood				
WYR (years)	40.0	40.0	40.0	30.0	30.0	40.0	50.0
WOODMAX (kg/m²)	.0121	.2710	.0638	.0520	.0520	.1776	.075
			10-hour dead wood branchwood				
WYR (years)	40.0	40.0	40.0	30.0	30.0	40.0	50.0
WOODMAX (kg/m²)	.833	.1548	.2619	.1879	.1879	.4294	.196
			100-hour dead woody branchwood				
WYR (years)	40.0	40.0	40.0	30.0	30.0	40.0	50.0
WOODMAX (kg/m²)	.1546	.1055	.5484	.5365	.5365	.7022	.546



* DKD – portion duff lost to microbial and faunal respiration
DKL – portion litter lost from microbial and faunal respiration
DKF – portion litter lost from overwinter decomposition
LTD – portion litter incorporated into duff
FALL – needlefall from conifer species on the plot

Figure 9—Diagram of litter and duff components. Inputs are noted by the downward-pointing arrows; outputs or losses are shown with upward-pointing arrows. This dynamic system is modeled using the coefficients DKD, DKL, DKF, FALL, and LTD.

Litter and duff loadings are calculated using annual dynamic equations in Kercher and Axelrod (1981). These equations are diagrammed in figure 9. The amount of annual needlefall ($FALL_i$) is calculated from the equation:

$$FALL_i = \Sigma(CW_i) * PFOL_i / NYR_i \tag{30}$$

where $\Sigma(CW_i)$ is the sum of crown weight over all trees of species i, $PFOL_i$ is the proportion of crown that is needles, and NYR_i is number of years needles remain on a tree of species i. Crown weight and $PFOL_i$ are estimated using regression equations provided by Brown (1976 and 1978). *NYR* values (table 1) are from Fowells (1965), Gottfried and Ffolliot (1983), Harlow and Harrar (1969), Smith (1972), Turner and Long (1975).

Needlefall (kilograms per square meter), the only input to litter-duff equations, is reduced by a species-dependent proportion (DKF_i) to account for overwinter decomposition (fig. 9). The remaining needlefall is added to the litter and subjected to further decomposition losses. A portion of the litter (DKL_i) is lost to the system while another portion (LTD_i) is added to the duff. Duff loading is then decreased by a decomposition proportion (DKD_i), and this decrement is also lost from the system. Decomposition losses in both litter and duff components are due to microbial and microfauna respiration. Each component is updated annually, and the total litter and duff loading for the stand is calculated by summing across all species. Values for DKF_i, DKL_i, LTD_i, and DKD_i for species i (table 1) are taken from Allison and Klein (1961), Edmonds (1979), Fahey (1983), Fogel and Cromack (1977), Jenny and others (1949), Kercher and Axelrod (1984), Klemmedson and others (1985), Gottfried and Ffolliot (1983), Maclean and Wein (1978), Means and others (1985), Meetenmeyer (1978), Piene and Van Cleve (1978), and Yoneda (1975).

Biomass for shrub and herbaceous fuel types are estimated separately using a function provided by Kercher and Axelrod (1984). The shrub and herbaceous equations are identical, except for internal parameters, and assume shrub and herb biomass on a site has an upper limit dependent on stand productivity. Annual change in biomass is a product of current biomass and a factor that limits growth as maximum biomass is approached. The equation is:

$$MASS_{m(y+1)} = MASS_{m(y)} + n^* MASS_{m(y^*)}[1-MASS_{m(y)} / BIOMAX_{m(j)}] *rAL \tag{31}$$

where $MASS_{m(y)}$ is biomass (kilograms per square meter) of fuel component m (shrub or herb) at year y, n is a growth constant for small biomass (per year), $BIOMAX_{m(j)}$ is maximum attainable biomass (kilograms per square meter) for fire group j in fuel component m, and rAL is the light response function presented in the tree growth section (equations 4 and 5). Values for n were taken as 1.44 per year for shrubs (Sampson 1944) and 10.842 per year for herbaceous fuel (from unpublished data collected by the authors). $BIOMAX_{m(j)}$ values (table 6) are from Brown and Bevins (1986), Irwin and Peek (1979), and Martin (1982).

Table 6—Parameter values for maximum biomass (BIOMAX) used to compute loadings of live and dead shrub and herbs in equation (31)

	Fire group number						
Component	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Shrub (kg/m²)	0.027	0.086	0.076	0.069	0.070	0.016	0.054
Herb (kg/m²)	.029	.048	.043	.102	.101	.142	.197

Using light response functions (rAL) from the Growth section, shrub and herbaceous loadings are divided into tolerant and intolerant categories. For example, the value for shade intolerant rAL (number between 0 and 1) is multipled by total shrub biomass to compute intolerant shrub biomass. Biomass estimates for the herbaceous shade tolerance categories are averaged, and then it is assumed that 90 percent of the average is dead at fire incidence. The remaining 10 percent is treated as live fuel. Shrubby biomass is also averaged across shade tolerance categories, but calculations of dead ($SDEAD$) and live ($SLIVE$) loadings (kilograms per square meter) are accomplished using these equations:

$$SDEAD = SAVE * (1 - PRO_j)/PLOTSIZ\ ; \quad \text{dead shrubby fuels (kg/m}^2\text{)} \tag{32}$$

$$SLIVE = SAVE * (PRO_j)/PLOTSIZ\ ; \quad \text{live shrubby fuels (kg/m}^2\text{)} \tag{33}$$

where $SAVE$ is the average loading (kilograms per square meter) for shade-tolerant and intolerant shrubs, PRO_j is the proportion of dead shrubby fuel in the total shrub biomass for fire group j, and $PLOTSIZ$ is the simulation plot size (square meters). Values for PRO_j (table 3) are from Brown and Bevins (1986).

Total depth of duff and litter (centimeters) is also calculated in subroutine FUEL using the equation:

$$DEPTH = 100 * [(LITT / LBULK_j) + (DUFF / DBULK_j)] \tag{34}$$

where $DEPTH$ is depth of duff and litter (centimeters), $LITT$ and $DUFF$ are the loadings (kilograms per square meter) of the litter and duff respectively, and $LBULK_j$ and $DBULK_j$ are the bulk densities of the litter and duff strata (respectively) for fire group j. Table 3 shows values of $LBULK_j$ and $DBULK_j$ taken from Brown (1981). This depth is then passed to subroutine BIRTH for use in the Boyce (1985) regression equations (equations 15 to 19).

Fire Characteristics (Subroutine FIRE)

Fire frequency is an input to FIRESUM. The user can specify number of years between fires (fire interval), an actual fire history for the stand consisting of variable fire intervals, or a stochastic function that computes fire interval as a dynamic variable using fire frequency probabilities (Kercher and Axelrod 1984). Fire year information is kept in a program array for reference during each year of program execution, similiar to the cone crop array mentioned in the Tree Regeneration section. This array remains unchanged between simulation runs. If the current simulation year is a fire year, fuel loadings and other input parameters are passed to subroutine FIREMOD and fire intensity is computed, then used to calculate scorch height for use in the fire mortality equation. Subroutine FIREMOD was developed by Albini (1976b) using Rothermel's (1972) model for predicting wildland fire spread. FIREMOD calculates Byram's fire line intensity (kilometers per hour) from a multivariate function comprised of the following user-specified parameters.

1. $WIND$ = windspeed at midflame height (kilometers per hour)
2. $SLOPE$ = slope of stand (degrees)
3. $MOIS_i$ = fractional moisture content of fuel type i
4. $RHOP_i$ = ovendry particle density for fuel type i (grams per cubic centimeter)
5. $BULK_j$ = bulk density of fuel bed in fire group j (grams per cubic centimeter)
6. SVR_{ij} = mean surface to volume ratio for fuel type i in fire group j (per centimeter)
7. LHV_i = heat content of fuel type i (kilojoules per kilogram)
8. ST_i = mineral content fraction of fuel type i
9. SE_i = silica-free mineral content fraction of fuel type i
10. $MEXT_i$ = moisture of extinction for fuel type i (fraction of weight)
11. $FLOAD_i$ = loading of fuel type i (kilograms per square meter)

Parameters having constant values across fuel components are $WIND$ (kilometers per hour), $MEXT$, and $SLOPE$ (degrees) taken from actual stand and site data and input into the model (appendixes B and C), and LHV (= 18586.7 kj/kg), ST (= 0.055), and SE (= 0.011) taken from Albini (1976a) and Anderson (1969). Other parameter values are in tables 7, 8, and 9. Variable $FLOAD_i$ is the only dynamic variable in the multivariate function, computed during program execution and passed to FIREMOD. Values for bulk densities and surface to volume ratios are taken from Brown (1970, 1981); particle densities from Brown (1970) and Anderson (1969); and moisture of extinction values from Frandsen and Andrews (1979) and Rothermel (1972). Values for moisture contents and windspeed are specified by the user and are usually taken from a typical fire prescription or fire weather prediction.

Table 7—Values for input parameters to subroutine FIREMOD stratified by fuel type component. MOIS is the fuel moisture content and RHOP is the surface to volume ratio

	Fuel component number							
Parameter symbol	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
MOIS (proportion)	0.08	0.08	0.10	0.14	0.10	0.08	1.00	1.50
RHOP (g/cm^2)	.51	.39	.39	.39	.51	.51	.51	.51

Table 8—Bulk densities (BULK) used in subroutine FIREMOD stratified by fire group

	Fire group number						
Parameter symbol	**1**	**2**	**3**	**4**	**5**	**6**	**7**
BULK (g/cm^3)	0.0158	0.0068	0.0080	0.0115	0.0071	0.0126	0.008

Table 9—Surface area to volume ratios (SVR) used in FIREMOD by fire group and fuel component

	Fuel component							
Fire group	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	57.41	8.89	3.48	0.95	3.156	91.86	49.20	91.86
2	57.41	11.76	2.88	.98	3.156	91.86	49.20	91.86
3	57.41	16.00	3.08	.98	3.156	91.86	49.20	91.86
4	57.41	16.00	3.08	.98	3.156	91.86	49.20	91.86
5	57.41	16.00	3.08	.98	3.156	91.86	49.20	91.86
6	57.41	16.00	3.08	.98	3.156	91.86	49.20	91.86
7	57.41	11.76	2.88	.98	3.156	91.86	49.20	91.86
8	57.41	11.76	2.88	.98	3.156	91.86	49.20	91.86

Fuel Consumption (Subroutine BRNOFF)

Fuel reduction by fire is computed using equations from Brown and others (1985), Norum (1974), and Sandberg (1980). The woody fuel reduction equations are:

1 and 10 hour timelag: $WOOD_{consumed} =$

$$0.890\,(WOOD_{pre}) - 0.0060 \tag{34}$$

100 hour timelag: $WOOD_{consumed} =$

$$0.845\,(WOOD_{pre}) - 0.0150 \tag{35}$$

Woody fuel reduction equations use preburn fuel loadings ($WOOD_{pre}$ in kilograms per square meter) to estimate fuel consumption ($WOOD_{consumed}$ in kilograms per square meter) independent of fire intensity or moisture content. The proportion of duff reduction, however, is based on preburn duff moisture content (*DMOIST* in percent). The equation for duff reduction is:

$DUFF_{post} =$

$$DUFF_{pre}\,[(83.7 - 0.426 * DMOIST)\,/100.0] \tag{36}$$

where $DUFF_{post}$ and $DUFF_{pre}$ are duff loadings (kilograms per square meter) postburn and preburn, respectively. A duff moisture content of 50 percent, typical of many fire prescriptions, was used in simulation runs. All litter, dead shrub, and herbaceous biomass is assumed to be consumed by fire, and the live shrub fuel loading was assumed to be reduced by 90 percent of preburn weight.

MODEL OUTPUT

FIRESUM stores average basal area for each tree species by simulation year in an external file. The program also stores fuel component loadings, duff depths, number of established seedlings, and fire behavior statistics. Any of these variables can be graphed against simulation time using various graphic software packages and related hardware (plotters). Figure 10 presents the graphed results of three contrasting simulation runs. The first run (10a and 10b) had fires occurring at 20-year fixed intervals, which could represent a typical prescribed burning scenario. The second run (10c and 10d) had fires occurring at an 8-year stochastic interval, which simulates pre-1900 fire frequency. And the last run (10e and 10f) is the result of a no-fire scenario (fire suppression). Tree species basal area, and fuel loadings are shown for the simulation plot.

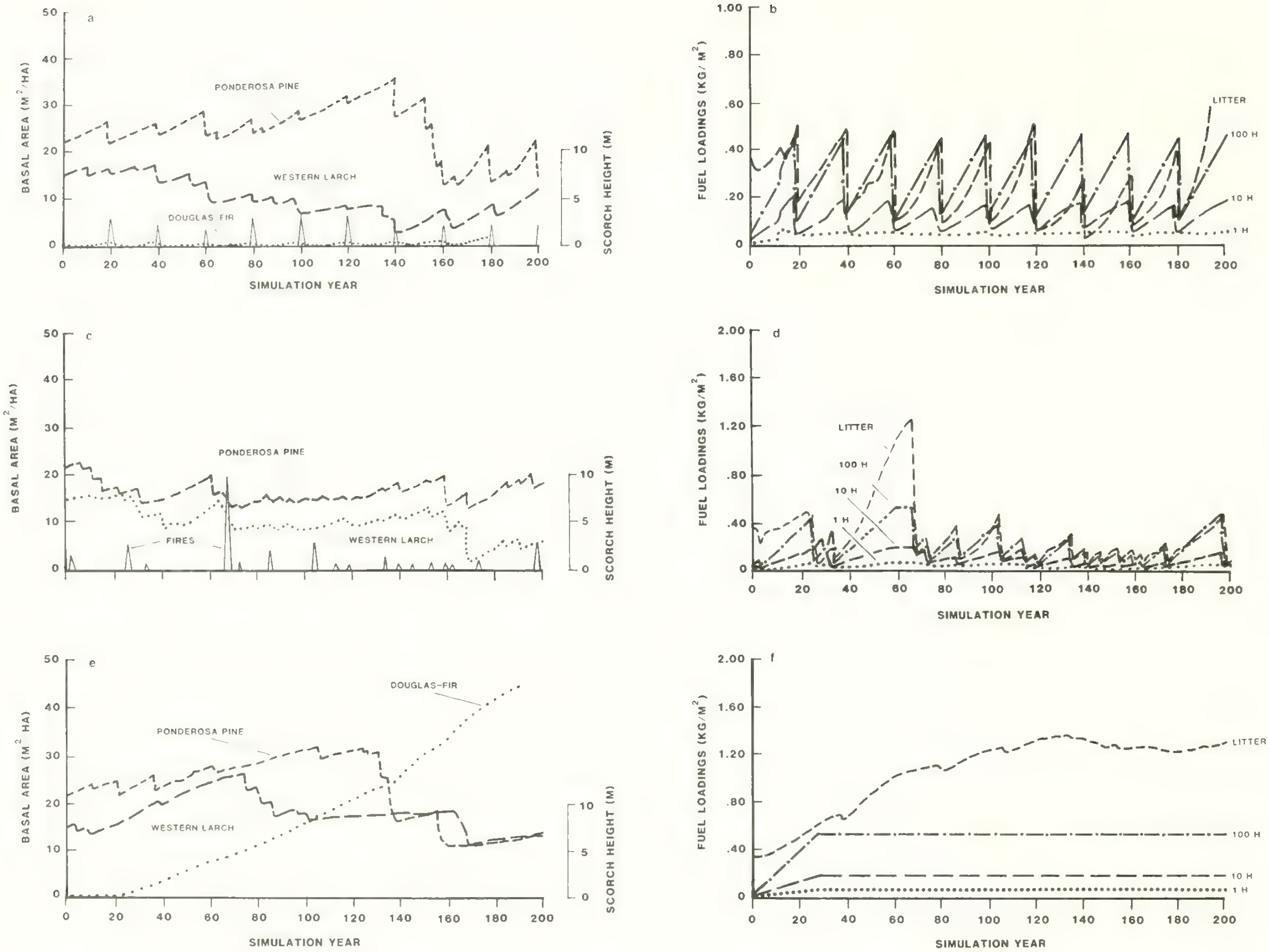


Figure 10 a-f—An example of FIRESUM outputs representing three possible fire scenarios. Graphs 10a and 10b show predicted basal areas and fuel loading for a 20-year fixed fire interval, respectively. Graphs 10c and 10d represent a stochastic fire interval having a mean of 8 years and graphs 10e and 10f predict basal areas and fuel loading in the absence of fires. All graphs are for the same simulation stand and simulate 200 years of ponderosa pine/Douglas-fir succession. Only four fuel components are graphed in 10b, 10d, and 10f: litter, 1-hour, 10-hour, and 100-hour timelage fuel classes. The scorch height of the fires in each scenario is illustrated by the spikes in graphs 10a, 10c, 10e with the corresponding scale located at the far right of these graphs.

MODEL TESTING AND ANALYSIS

Validation and Verification

Testing succession simulation models requires extensive stand data collected at one or more widely separated intervals during successional development. Acquiring these data can be difficult. To test or verify FIRESUM we employed a combination of two methods. The first method was to search the literature for long-term data compatible with the inputs and outputs of FIRESUM. Verification data must have density, age, and diameter (d.b.h.) measurements on trees by species by unit area. These data must have another set of measurements at least 25 to 30 years later, or age-diameter relationships so that regression equations can be developed and used to project a present stand forward or backward in time (Habeck 1985, Keane and others 1989a). The model is then used to simulate conditions measured by these historic data.

The second method of verification involved sampling two adjacent stands on one site. One stand is a mature forest while the other has resulted from a wildfire (disturbance stand). Tree densities, ages, diameters (d.b.h.), and enviromental variables (elevation, aspect, slope, soil depth, etc.) are recorded for each stand (example shown in table 10). The sampled values from the mature stand are used as inputs to FIRESUM. The model is then used to simulate effects of a wildfire on the input stand and grow a subsequent simulation stand of the same age as the

Table 10—Example site and environmental conditions for the ponderosa pine/ Douglas-fir stand used in a FIRESUM execution

Input parameter	Value
Site Description	
Elevation (m)	1,256.0
Slope (degrees)	8.0
Depth to bedrock (ft)	2.5
Water holding cap. (cm/m)	133.3
Fire group	6.0
Fire Weather	
Ambient temperature (°C)	20.0
Wind (km/hour)	3.2
Relative humidity (%)	40.0
Fuel Moisture Contents	
1-hour fuel moisture (%)	8.0
10-hour fuel moisture (%)	10.0
100-hour fuel moisture (%)	14.0
Litter moisture (%)	8.0
Duff moisture (%)	50.0
Dead shrub moisture (%)	10.0
Dead herbaceous moisture (%)	8.0
Live shrub moisture (%)	150.0
Live herbaceous moisture (%)	100.0

Table 11—Results of three tests on the fire succession model FIRESUM

Test	Ecosystem	Basal area	Fuel loading
		- - - *Percent*	*inaccurate* [1] - - -
Test 1	Ponderosa pine/Douglas-fir	12.2	14.6
Test 2	Whitebark pine/subalpine fir	16.2	10.5
Test 3	Whitebark pine	15.5	11.2
Average percentage inaccurate		14.6	12.1

[1]Variable basal area includes basal area for all species on simulation plot. Fuel loading is the total fuel loading (all six fuel components) for the plot. Percentage inaccurate indicates the difference in percentage of the observed from the predicted.

sampled disturbance stand. Results of the simulation are compared with the sampled values from the disturbance stand. The model can be refined or calibrated based on verification results.

Three verification tests have been administered to FIRESUM (table 11) (see Keane and others in press a, in press b). Test results indicated FIRESUM underpredicts basal areas and overpredicts fuel loadings. This is probably due to inaccurate quantification of the parameters involved in the algorithms. Also, site parameters measured for the sample stand could have been in error and model parameters might not have been adequate for these sample sites. These parameters were taken from the literature and may not be applicable to the area or to the site where the test plot was located.

Sensitivity Analysis

A sensitivity analysis of FIRESUM was performed by increasing a selected parameter by 10 percent of its original value and executing the model while holding all other parameters constant. Computer costs and time constraints limited basal area predictions to the average from 30 simulation runs Kelcher and Axelrod 1954). Standard deviations of basal area averaged from 30 runs were below 0.5 m^2/ha; small enough to discern the relative sensitivity of various parameters.

Results of the sensitivity analysis (table 12) agreed closely with those found by Kercher and Axelrod (1984). Maximum age for a tree species ($AGEMAX_i$) was clearly

Table 12—Results of the sensitivity analysis[1]

Parameter		Percent change in PIPO basal area	
Symbol	Description	50 years	100 years
AGEMAX	Maximum age of species	–17.50	–18.10
WOODMAX	Maximum woody fuel loading	–1.41	–.89
SPM	Maximum stocking of seedlings	–1.03	–2.33
DBULK	Bulk density of duff-litter	+1.61	+3.78
WSO	Minimum AET:PET of a species	–7.25	–5.11
DMIN	Minimum number degree-days	–11.34	–7.37
DMAX	Maximum number degree-days	–1.65	+.34
BARMAX	Maximum basal area	+10.01	+11.24
Dm	Maximum diameter	+9.98	+8.86
Hm	Maximum height	+5.01	+2.00
NYR	Years needles stay on tree	+.96	–1.04
DKL	Proportion of decay in litter	+.23	+.36
AINC	Minimum growth rate for mortality	–1.06	–3.11

[1]Values in table are percentage change in ponderosa pine basal area when parameter listed in first column is increased by 10 percent. Sensitivity is measured at the 50th and 100th year of simulation and is calculated from the average of thirty simulation runs.

the most sensitive parameter measured, due to its presence in both the growth and mortality algorithms. In general, parameters directly related to the theoretical growth equation seemed to be the most crucial in FIRESUM. Parameters involved in the calculation of tree regeneration were also important.

An additional, and more extensive, sensitivity analysis was performed for some parameters used in the fire module (FIREMOD). In this analysis, three sets of fuel moisture values for each of three size classes of woody fuel were entered into the model to evaluate overall effect on plot basal area. This process was repeated for three duff moisture values. Results show that dry fuels resulted in an increase in the basal area of ponderosa pine (table 13), presumably because fires ignited in dry fuels tend to be hotter than those ignited in moist fuels. These hotter fires apparently eliminated competing conifers and shrubs, thus allowing greater pine productivity. When duff moisture content was high, very little duff was removed by fire; this adversely affected regeneration of ponderosa pine, and to a lesser degree, Douglas-fir.

Table 13—Sensitivity analysis of fuel moisture values in FIRESUM

Moisture class	Duff moisture content	Ponderosa pine basal area (m^2/ha)[2] 25 yr	50 yr	100 yr
DRY	0.25	24.42	21.85	15.03
MOIST	.25	23.91	22.43	16.72
WET	.25	22.83	23.37	17.62
DRY	.75	19.68	17.34	13.08
MOIST	.75	21.75	18.68	15.30
WET	.75	22.44	22.44	17.50
DRY	1.50	22.91	20.32	15.34
MOIST	1.50	19.77	21.74	16.37
WET	1.50	19.34	22.88	17.24

[1]Fuel moisture contents are for woody fuel components only. The 1-, 10-, and 100-hour timelag moisture contents for the three moisture classes are: DRY (0.05, 0.05, 0.08), MOIST (0.12, 0.12, 0.16), and WET (0.19, 0.19, 0.24).
[2]Values are averages of ponderosa pine basal area from 30 simulation runs. Basal area was recorded for the 25th, 50th, and 100th year of simulation.

SUMMARY AND CONCLUSIONS

FIRESUM is similar to SILVA and many other JABOWA-type models in concept, but it is unique in construction. Related environmental components were integrated in FIRESUM so they depend on each other. Additional ecological processes such as woody fuel accumulation and duff depth-regeneration interaction were added to more completely simulate growing conditions in ponderosa pine/Douglas-fir ecosystems. The fuel and fire submodules were refined to more accurately predict fire behavior, and the regeneration algorithm was extensively modified to account for the role of site conditions in seedling mortality. Because site parameters in FIRESUM were stratified by habitat type groups (fire groups), many stands of differing species and site conditions may be modeled. Lastly, the FIRESUM program was modified by making fuel moisture and other site variables inputs to the program.

FIRESUM could be further modified to more accurately simulate ecological processes. The regeneration algorithm could be reworked to account for additional stochastic elements contributing to seedling establishment (Keane and others in press a, in press b). Cone crop size, seed dissemination, seed germination, and seed lost to birds and animals could be linked to weather and soil conditions. The fuel accumulation and decomposition algorithm could be improved. Currently, FIRESUM does not simulate accumulation and decomposition in woody, shrubby, and herbaceous fuels, as it does for litter and duff. Quantification of decomposition rates in all fuel components and linking the decomposition rates to climatic processes (for example, AET:PET ratio) would enhance the model's predictive value.

Another possible modification would be to develop a more intensive growth equation. The use of growth reduction factors may not allow sufficient resolution to accurately predict subtle changes in tree growth. The fire subroutines could also be modified to account for tree mortality due to crown fires or to root damage, duration of fire and its effect on tree mortality, vertical fire propagation, contribution of large fuels to fire intensity and tree mortality, and reduction of shrub and herbaceous fuels. Other changes might be to more intensively model the effect of soil fertility and water stress on tree growth, develop more accurate leaf area equations, link tree establishment and growth to understory shrub and herbaceous cover, and include off-site seed sources in the regeneration subroutine. Lastly, a wide range of stands with long-term measurements are needed to more accurately estimate the variablity of model predictions.

With the addition or modification of subroutines, FIRESUM could be applied to a broad range of ecological problems in the Inland Northwest. One possible application is to assess the effect of climatic change on tree growth and fire intensity and frequency. Climatic input parameters could be modified using current models that simulate changes in temperature and precipitation over time. Changes in photosynthetic activity due to the "greenhouse effect," increased carbon dioxide, increased temperature, and decreased water availablity, could be simulated by introducing another reduction factor in the growth algorithm. Climatic effects on fire frequency would have to be stochastically linked to the vegetation complex and site environment. FIRESUM might enable us to predict shifts in species composition and structure if the global climate is indeed changing as many scientists contend.

Another important application of FIRESUM is in increasing understanding of ecological processes. Such an understanding could ultimately aid natural resource management. For example, a land manager might wish to use FIRESUM to evaluate cumulative effects of different prescribed burning schedules on tree composition and structure. Other potential uses include assessment of insect- and disease-caused tree mortality related to fire frequency, prediction of stand productivity at varying fire frequencies, and evaluation of wildlife habitat potential under different fire regimes.

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APPENDIX A: LISTING OF THE FORTRAN77 COMPUTER CODE FOR THE MODEL/PROGRAM FIRESUM

```
      PROGRAM FIRESUM
C ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C           Model for simulation of western conifeous forests.            *
C This version was coded by Bob Keane, Quantitative Ecologist.            *
C Modifications and alterations to original SILVA were accomplished by    *
C                           Bob Keane                                     *
C  please contact Bob Keane for information on its use                    *
C               Keane:                                                    *
C                PO Box 8089                                              *
C                USFS Fed. Bldg.                                          *
C                Missoula, MT  59806                                      *
C                406-329-3390                                             *
C                fts: 585-3390 OR 584-4867                                *
C                com: 406-329-4837 or 406-329-3390                        *
C *********************************************************************** *
C ************      FIRESUM: Keane version June 6, 1989         ******** *
C ************ Fire effects in Ponderosa pine-Douglas-fir stands******** *
C ************ Fire effects in Whitebark pine forests          ******** *
C *********************************************************************** *
C         FIRESUM coding is an extensive modification of jabowa           *
C               botkin et. al. j. ecol. 60:849-872 (1972).                *
C          ****************************************************           *
C               ***********notice to users**************                  *
C          SUBROUTINEs birth,dist,kill,cycles, and rings use the          *
C          random number generator rgen.  this is called as XRANDOM,      *
C          where x is a returned array of random numbers between          *
C          0 and 1 and n is the number of returned values of x.           *
C          rgen and the seed generator ranst are at the END of the        *
C          deck.  ranst is called once at the beginning of the job        *
C          to set the seed for rgen.  the user should replace these       *
C          SUBROUTINEs with his own random number generator.              *
C          Input files should have names:tredat,sitdat,and contrl.        *
C          Unit numbers are: 1-tredat.dat,2-sitdat.dat,3-contrl.dat.      *
C                     **************************                          *
C Modification of FIRESUM                                                 *
C     Value of nj in birth rounded instead of trun                        *
C     Polar method used to generate gauss r.v. in birth                   *
C Corrections to SUBROUTINE site and input of tree water response         *
C     in SUBROUTINE tree                                                  *
C     SUBROUTINE grow and birth modified for water stress                 *
C     still use botkins thornthwaite method                               *
C     this version has option of suppression effects of water stress      *
C            nwtstr = 1 water stress exists                               *
C            0 no water stress, optimum growth                            *
C This version prints out results in units of sq. m./ha. orsq.cm/sq.m.    *
C This version uses three scratch arrays and uses them in shade also.     *
C This version sets limit of 3000 trees.                                  *
C This version has been cleaned for sending to fws                        *
C This version has fortran random number generator XRANDM,only            *
C                 for export.                                             *
C This version is now ansi compatible for export.                         *
C This version replaces rnfl in dist with rgen                            *
C                                                                         *
C Dynamic Variables:                                                      *
C   AGE(j) - vector of tree ages (years)                                  *
C   DBH(j) - vector of tree diameters (cm)                                *
C   OCCUR(j) - binary vector of fire years (0 or 1)                       *
C   DEGD - number of degree days for simulation plot.                     *
C   SLA(j) - vector of tree leaf areas (m2/m2)                            *
C   NTREES(i) - species vector for number of trees per species.           *
```

```
C   NTREES(i) - species vector for number of trees per species.        *
C   TABLE(j) - table of possible seed years for every species.         *
C   S1(j),S2(j),S3(j) - working arrays for program execution.          *
C   NDEAD(i) - number of dead trees per species.                       *
C   DDBH(j) - working vector for tree dbh.                             *
C   ABAR(j) - vector of basal areas for trees (m2/ha)                  *
C   PD(j) - probability of survival for each i tree.                   *
C Input Variables:                                                     *
C   ASIDE(i) - allsided to projected leaf area conversion factor.      *
C   C(7) - Coefficient in crown weight equations.                      *
C   ALPHA(7) - Coefficient in crown weight equations.                  *
C   B2(7) - calculated coefficient for height equation.                *
C   B3(7) - calculated coefficient for height and growth equation.     *
C   CEXT(8) - extinction factor for each fire group canopy.            *
C   CRAT(7) - live crown ratio for each species.                       *
C   SIGMA(7) - parameter for converting crown weight to leaf area.     *
C   AP(7) - alpha regression coefficient for                           *
C   BETAP(7) - beta regression coefficient for                         *
C   G(7) - calculated growth parameter for diameter increment.         *
C   AGEMX(7) - maximum attainable age by species.                      *
C   DM(7) - maximum attainable diameter by species.                    *
C   HM(7) - maximum attainable height by species.                      *
C   SPM(8) - maximum attainable seedling stocking by fire group.       *
C   XMBAR(8) - maximum attainable basal area by fire group.            *
C   PHI - maximum relativized available light (=1.0)                   *
C   DMIN(7) - minimum number of degree days by species.                *
C   DMAX(7) - maximum number of degree days by species.                *
C   DOPT(7) - optimal number of degree days by species.                *
C   BASET(12) - temperature by month (oC).                             *
C   BASEP(12) - precipitation by month (cm).                           *
C   BASEH - base elevation or elevational difference from w.s. to plot.*
C   ROCK - percent of exposed rock on plot.                            *
C   TILL - depth of soil in meters.                                    *
C   TEXT - soil water holding capacity in mm/m.                        *
C   EXCESS - prop of precip that is runoff.                            *
C   PLTSIZ - area of simulation plot (m2).                             *
C   IFG - fire group number.                                           *
C   SURA(7) - alpha coefficient for seedling survival equations.       *
C   SURB(7) - beta coefficient for seedling survival equations.        *
C   DBULK(8,2) - bulk density of litter and duff by fire group.        *
C   ISHADE(7) - shade tolerance by species.                            *
C   IMOIST(7) - moisture tolerance by species.                         *
C   MEXT(2) - moisture of extinction by live or dead fuel class.       *
C   RHOP(7) - fuel particle density for each fuel component.           *
C   BULK(2,8) - bulk densities for live and dead fuel by fire group.   *
C   MOIS(2,7) - moisture content of live and dead fuel components.     *
C   MPS(2,7) - surface area to volume ratio for live and dead comp.    *
C   LHV(2,7) - latent heat content of each fuel component.             *
C   ST(2,7) - fraction mineral content of dead fuel.                   *
C   SE(2,7) - fraction mineral content of fuel excluding silica.       *
C   DKD(7),DKL(7),DKF(7),LTD(7) - decomposition proportions for litter.*
C   ABM(7),FFL(7) - parameters quantifing litterfall loadings.         *
C   DMOIST - duff moisture content.                                    *
C   NS - number of species.                                            *
C   NSPAN - time span (in years) to simulate.                          *
C   NRUNS - number of times to repeat each simulation time span.       *
C   CLRCUT - flag indicating if stand originated as a clearcut.        *
C   NWRSTR - flag indicating if water stress factors are included.     *
C   IFIRE - number of years between fires (fire interval).             *
C   SBURN - proportion of burnable live shrubs.                        *
```

```
C   BC(7) - bark thickness conversion factor by species.                *
C   D1(7),D2(7),D3(7) - coefficients in fire mortality equation.        *
C   FWG(2,7) - working array for fuel loadings by component.            *
C   WOOD(3) - woody fuel loading by size class 1,10,100 hr.             *
C   NDYR(7) - number years needles stay on tree of species i.           *
C   CROP(7) - number of years between good cone crops.                  *
C   CBLOCK(7) - number of years before a good cone crop can occur.      *
C   GRWS(7) - growth reduction from water stress.                       *
C   GRF(7) - growth reduction from pollution.                           *
C This program calls 45 subroutines and 3 functions, consists of about *
C 3000 lines of code, and is written in FORTRAN 77.                     *
C ***********************************************************************
      common/leaf/aside(7),c(7),alpha(7),b2(7),b3(7),cext(8),crat(7),
     &            sigma(7),ap(7),betap(7)
      common/trunk/g(7),agemx(7),dm(7),hm(7),spm(8),ysc(7)
      common/hdata/phi,xmbar(8),degd,ainc(7),binfest(8),ibcycle(8),brr
      common/climat/ dmin(7),dopt(7),dmax(7),baset(12),basep(12),baseh
      common/water/grws(7),ws0(7),wsm(7),nws(7),wr,grdd(7),grbar(7)
      common/plotq/elev,rock,till,soilm,text,excess,pltsiz,ifg
      common/birthk/sura(7),surb(7),dbulk(8,2),disequ(2,7),rdelay(8)
      common/types/ishade(7),imoist(7),spp(7)
      common/wbark/ cmax,agecon,dbhmin,birds,spc,spcac,cyr(4),fmax,cpt,
     &              pfind,ssc
      common/fuel1/ mext(2),rhop(2,7),bulk(2,8),mois(2,7)
      common/fuel2/ mps(2,7),lhv(2,7),st(2,7),se(2,7)
      common/fuel3/ dkl(7),dkd(7),dkf(7),ltd(7)
      common/fuel4/ abm(7),ffl(7),fyr(3,8),fload(3,8)
      common/fuel5/ amc(7),bmc(7),cmc(7),dmc(7),mmc(7),tmc,emc(7)
      common/cfire/cbd(7),vfl(7),cfmc(7),vfmc(7),cflm(7),csvr(7),
     &             vsvr(7),bl(7)
      common/sites/ occur(500),rh,wind,ttheta,t
      common/mort/ d1(7),d2(7),d3(7),bc(7)
      common/polut/ndyr(7),dmoist
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      common/init/ ntrees0(7),dbh0(4000),ncount(20,7),nbins,width,
     &             age0(4000),agein(20,7)
      common/limits/ mxtrs,maxspc,mxdd,mxyrs,maxbin
      real mext,lhv,mmc,mps,ltd,mois,emc,cyr
      real dbh(4000),sla(4000),pd(4000),fwg(2,7),wood(3),ptree(7),
     &     dsw(7),dsize(7)
      real s1(4000),s2(4000),s3(4000),crop(7)
      real grf(7),area(4500),abar(4500),age(4000)
      integer table(4500),ntrees(7),ndead(7),cblock(7),clrcut,occur
      integer fyr,itop(4000)
      character*1 ishade,imoist,spp*4

      open(unit=5,file='OUTFILE.DAT',form='formatted',recl=150,
     &     pad='yes')

      nl = 2
      npine = 0
      lag = 0
      branch = 0.0
      iseed = 0
      icwf = 0

C ..... Call to initialize random number generator user should
C ..... introduces his own random number generator
      xran = rrand()
```

```
      call sitdta
      call tree(nl,crop,cblock)
      call calcnt
      call cntrl(dsize,dimax,dimin)
      call dist(s1,itop)
      nyears= nspan
      nsp= ns
      do 5 i = 1,ns
           dsw(i) = 0.0
           if(dsize(i) .lt. 0.0) dsw(i) = abs(dsize(i))
           if(dsize(i) .gt. 0.0) dsw(i) = sqrt(5000.0*dsize(i)*3.14159)
    5 continue

      call site

      close(5)

      open(unit=8,file='WOOD.DAT',pad='yes',recl=80)
      open(unit=9,file='BRUSH.DAT',pad='yes',recl=80)
      open(unit=11,file='FIRE.DAT',pad='yes',recl=80)
      open(unit=12,file='DUFF.DAT',pad='yes',recl=100)

      do 10 i = 1,nruns
           irun = i
           if(irun .eq. 2) then
                close(8)
                close(9)
                close(11)
                close(12)
           endif
           print *,'FIRESUM run number: ',i
           iseed = 0
           call cycles(table,nyears,nsp,s1,crop,cblock)
           call rings(nyears,s1)
           call starter(ntrees,dbh,age)
           do 20 k = 1,nspan
                kyr = k
                call birth(ntrees,dbh,age,s1,s2,table,nyears,kyr,duff,
     &                      irun,itop,dsw,ccrop,lag,iseed,ptree)
                call pollut(grf,kyr)
                call grow(dbh,pd,ntrees,sla,grf,s1,s2,s3,age,kyr,itop,
     &                     inend,npine)
                call fire(ntrees,dbh,fwg,nl,pd,kyr,duff,branch,wood,
     &                     irun,icwf,dimax,dimin)
                if(icwf .eq. 1) iseed = 1
                call kill(ntrees,ndead,dbh,pd,s1,age,branch,itop,
     &                     icwf)
                call basal(ntrees,dbh,kyr,nyears,area)
                if(icwf .eq. 1) then
                     lag = kyr + ifix(rdelay(ifg))
                endif
   20      continue
           nm= nspan*ns
           call avg(area,abar,nm)
   10 continue

C ..... printing annual basal area projections
      call output(abar,nyears)

      stop
```

```
      END
      BLOCKDATA
C *************************************************************************
C  BLOCK DATA FOR SIMULATION RUN SPECIFICS
C     These numbers set operating limits on model:
C     mxtrs....... maximium number of trees allowed on the stand
C     mxyrs....... max number of years in one "run" of the model
C     maxbin...... max num of diam cohorts in initial dist of tree sizes
C     maxspc...... max number of tree species
C     mxyrs....... maximum number of years  the model may run
C ************************************************************************
      common/limits/ mxtrs,maxspc,mxdd,mxyrs,maxbin

      data mxtrs/4000/
      data mxdd/4000/
      data mxyrs/500/
      data maxbin/20/
      data maxspc/7/

      END
      SUBROUTINE add(x,nx,xnew,new,k)
C ************************************************************************
C This subroutine adds new trees to the DBH array (x(i,j)) in the
C appropriate species and DBH slots.  This subroutine is called from
C BIRTH and adds seedlings 137 cm tall and 1.0 cm diameter.
C ************************************************************************
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      integer clrcut
      dimension x(1),nx(1),xnew(1)

C ..... Add the elements of xnew to x after species k
C ..... nx array  is not updated
      if (new.eq.0) return
      n= isum(nx,ns)
      kk= isum(nx,k)
      nkk= n-kk
      if (nkk.eq.0) go to 15
      do 10 j= 1,nkk
            x(n+new-j+1)= x(n-j+1)
   10 continue
   15 continue
      do 20 j= 1,new
            x(kk+j)= xnew(j)
   20 continue

      return
      END
      SUBROUTINE avg(x,xbar,n)
C ************************************************************************
C This subroutine averages the annual estimates of basal area for
C every run.  This is a running average and variance is not computed.
C ************************************************************************
      dimension x(1),xbar(1)
      integer count
      data count/0/

      count= count+1
      w1= float(count-1)/float(count)
      w2= 1./float(count)
```

```
C ..... Estimate the average and include in array
      do 10 i= 1,n
            xbar(i)= w1*xbar(i)+w2*x(i)
   10 continue
      return
      END
      SUBROUTINE basal(ntrees,dbh,kyr,nyears,area)
C *********************************************************************
C * Subroutine basal keeps a continous account of species basal     *
C * area by simulation year.  These values are stored in working    *
C * array AREA(i,j) to be printed in subroutine OUTPUT.             *
C *********************************************************************
      common/plotq/elev,rock,till,soilm,text,excess,pltsiz,ifg
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      integer clrcut
      dimension ntrees(1),dbh(1),area(nyears,1)
      data pi/3.141592654/

      do 10 k= 1,ns
            nk= ntrees(k)
            area(kyr,k)= 0.
            if (nk.eq.0) go to 10
            if(k .eq. 1) then
                 jj = 0
            else
                 jj= isum(ntrees,k-1)
            endif
            do 20 j= 1,nk
                 area(kyr,k)= area(kyr,k)+dbh(j+jj)**2.0
   20     continue

C ..... Compute the basal area for the plot in meters square
          area(kyr,k)=area(kyr,k)*pi/(4.*pltsiz)
   10 continue
      return
      END
      SUBROUTINE beetle(SPP,DIA,AGE,PROB)
C ***********************************************************************
C This subroutine simulates tree mortality if tree is infested with  *
C bark beetles.  The current functions are from data collected from  *
C the gallatin by Region 1 personnel - contact Ammens Ogden          *
C ***********************************************************************
      character spp*4

C ..... Compute the probability of mortality by species
      if(spp .eq. 'pial') then
            prob = ((0.7664 * dia) - 0.2222) / 100.0
            if(prob .lt. 0.0) prob = 0.0
            if(prob .gt. 1.0) prob = 1.0
      elseif(spp .eq. 'pico') then
            if(dia .lt. 46.0 .and. age .lt. 150.0) then
                 prob = (0.555 * dia) / 100.0
            else
                 prob = 0.10
            endif
      elseif(spp .eq. 'pipo' .or. spp .eq. 'pimo') then
            if(dia .lt. 46.0) then
                 prob = (0.555 * dia) / 100.0
            else
                 prob = 0.10
```

```
           endif
      else
           prob = 1.0
      endif
      return
      END
      SUBROUTINE birth(ntrees,dbh,age,ds,agnw,table,nyears,kyr,duff,
     &                 irun,itop,dsw,ccrop,lag,iseed,ptree)
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C  This subroutine adds new trees to plot based on climatic constraints
C  (degree-days,available water,cone crop) and site factors (shading and
C  duff depth).  Tree incursion is at 8 years and 1 cm dbh.
C
C     spm(j) ..... max number of new seedlings per meter for all species
C     fnj(j) ..... number of seedlings established onsite.
C     psur   ..... percent survival calculated from duff depth (Boyce 86)
C     dsw    ..... distance to seed wall in meters
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      real dbh(1),ds(1),agnw(1),age(1),ptree(7)
      real u(2),dsbar(7),sigds(7),sregen(7),dsw(7)
      integer clrcut,table(nyears,1),ntrees(1),itop(1)
      character*1 ishade,imoist,spp*4
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      common/limits/ mxtrs,maxspc,mxdd,mxyrs,maxbin
      common/water/grws(7),ws0(7),wsm(7),nws(7),wr,grdd(7),grbar(7)
      common/leaf/aside(7),c(7),alpha(7),b2(7),b3(7),cext(8),crat(7),
     &            sigma(7),ap(7),betap(7)
      common/trunk/g(7),agemx(7),dm(7),hm(7),spm(8),ysc(7)
      common/climat/ dmin(7),dopt(7),dmax(7),baset(12),basep(12),baseh
      common/hdata/phi,xmbar(8),degd,ainc(7),binfest(8),ibcycle(8),brr
      common/birthk/sura(7),surb(7),dbulk(8,2),disequ(2,7),rdelay(8)
      common/plotq/elev,rock,till,soilm,text,excess,pltsiz,ifg
      common/types/ishade(7),imoist(7),spp(7)
      data dsbar/7*.5/,sigds/7*0.1/,no/0/

C ..... Initialize important variables
      if(kyr .eq. 1) duff = 1.5
      do 5 i = 1,ns
          sregen(i) = 0.0
    5 continue
      cones = 0.0
      seedlng = spm(ifg)
      fnjsum = 0.0
      dred = 1.0

C ..... Delay regeneration for interval based on fire group
      if(lag .gt. kyr) then
          go to 200
      endif

C ..... Start the regeneration process for each species
      do 100 j= 1,ns
          nj= 0
          sla= 0.

C ..... Climatic and cone crop tests
          if (table(kyr,j) .eq. no)  go to 100
          if (degd .lt. dmin(j))     go to 100
          if (degd .gt. dmax(j))     go to 100
          if (grws(j) .le. 0.0)      go to 100
```

```
          if (wr .lt. ws0(j))        go to 100

C .....Seedlings to be established.  Reduction factors now calculated
          psur = (sura(j) - surb(j) * duff) / sura(j)
          if(psur .lt. 0.0) psur = 0.0
          totsla = 0.0
          totree = 0.0
          do 10 ii = 1,ns
               if(lag+ysc(ii) .lt. kyr) iseed = 0
               if(iseed .eq. 0) ptree(ii) = 0.0
   10     continue
          do 20 kk= 1, ns
               nkk= ntrees(kk)
               if (nkk.eq.0) go to 20
               kkkk = kk - 1
               kkk = kk
               if(kk .eq. 1) then
                    ikk = 0
               else
                    ikk= isum(ntrees,kkkk)
               endif
               call needle(sla,ikk,nkk,dbh,kkk,wgt,pltsiz)
               totsla = totsla + sla

C ..... Calculation of proportion of seed trees
               do 15 ii = 1,nkk
                    if((dbh(ii+ikk) .gt. 10.0 .or. age(ii+ikk) .ge.
     &              ysc(kk)) .and. iseed .eq. 0) then
                         ptree(kk) = ptree(kk) + 1.0
                         totree = totree + 1.0
                    endif
   15          continue
   20     continue

C ..... Adjustment for off-site seeding, and then the seedling equation
          if(iseed .eq. 0) then
               if(totree .gt. 0.0)    ptree(j) = ptree(j) / totree
               if(totree .le. 0.0)    ptree(j) = 0.05
               if(ptree(j) .lt. 0.05) ptree(j) = 0.05
          endif

C ..... Calculation of whitebark pine seedlings if species present
          if(spp(j) .eq. 'pial') then
               call pinalb(fnj,totsla,dbh,age,ntrees,itop,ccrop,cones)
               seedlng = seedlng - (fnj / pltsiz)
               if(seedlng .le. 0.0) seedlng = 0.1
          endif

C ..... Reduction of seedling due to distance from seed source
   30     dred = 1.0
          if(dsw(j) .gt. 20) then
               if(ptree(j) .le. 0.01) then
                    if(spp(j) .eq. 'pial') then
                         xdist = dsw(j) - 20.0
                         if(xdist .le. 0.0) xdist = 0.0
                         dred = 10.0**(-0.8062-(0.000454*xdist)) /
     &                          0.1563
                         if(dred .lt. 0.0001) dred = 0.0001
                    else
                         xdist = (dsw(j) - 20.0) * 3.2808
```

```
                             xmax = abs(disequ(1,j) / disequ(2,j)) / 3.28
                             if(xdist .le. 0.0) xdist = 0.0
                             if(xmax .gt. xdist) then
                                  dred = exp(disequ(1,j) + disequ(2,j)
     &                                   * xdist) / exp(disequ(1,j))
                                  if(dred .lt. 0.00001) dred = 0.00001
                             else
                                  dred = 0.00001
                             endif
                        endif
                   endif
              endif

C ..... Calculation of number of seedlings for species j
              if(spp(j) .ne. 'pial') then
                   fnj = seedlng * pltsiz * psur * ptree(j) * dred
              else
                   fnj = seedlng * dred
              endif

C ..... Reduction for shading effects by tolerance class
             if(ishade(j) .eq. 'I') fnj=fnj * exp(-0.8*totsla)
             if(ishade(j) .eq. 'M') fnj=fnj * exp(-0.25*(totsla+1.0))
             if(ishade(j) .eq. 'T') fnj=fnj * (1.0-exp(-0.25*(totsla+0.2)))

C ..... Final calculation of number established seedlings
              ntot= isum(ntrees,ns)
              xred = (1.0 - (float(ntot) / float(mxtrs)))
              if(fnj .gt. 100.0) fnj = 100.0
              fnj = fnj * xred
              sregen(j) = fnj
              fnjsum = fnjsum + fnj
              nj= int(fnj+.5)
              if(nj.eq.0) go to 100

C ..... Check to see if number of trees has not exceeded maximum
              if (ntot+nj.gt.mxtrs) call error(9)

C ..... Calculate a random diameter for each of the nj seedlings
            do 40 i= 1,nj
              hsbar= b2(j)*dsbar(j)-b3(j)*dsbar(j)**2-b3(j)*sigds(j)**2
              sighs= (b2(j)-2.*b3(j)*dsbar(j))*sigds(j)
   45         call rgen(u,2)
              u(1)= 2.*u(1)-1.
              u(2)= 2.*u(2)-1.
              s= u(1)**2+u(2)**2
              if (s.ge.1) go to 45
              z= u(1)*sqrt(-2.*alog(s)/s)
              hs= sighs*z+hsbar
              if (hs.lt.0.) go to 45
              ds(i)= (b2(j)/(2.*b3(j)))*
     &              (1.-sqrt(1.-4.*(b3(j)/b2(j)**2)*hs))
   40       continue

C ..... Place the seedling in appropriate cell in DBH and AGE array.
            ijj = j
              call add(dbh,ntrees,ds,nj,ijj)
              do 50 k= 1,nj
                   agnw(k)= rdelay(ifg)
   50         continue
```

```
            call add(age,ntrees,agnw,nj,ijj)

C ..... Put zero into the blister rust array ITOP
            n= isum(ntrees,ns)
            kk= isum(ntrees,ijj)
            nkk= n-kk
            if (nkk.eq.0) go to 65
            do 60 i= 1,nkk
                itop(n+nj-i+1)= itop(n-i+1)
   60       continue
   65       do 70 i= 1,nj
                itop(kk+i)= 0
                if(spp(j) .eq. 'pial' .or. spp(j) .eq. 'pimo') then
                    rnum = rnd()
                    if(rnum .lt. brr) itop(kk+i) = 2
                endif
   70       continue
            ntrees(j)= ntrees(j)+nj
  100 continue

C ..... Writing important regeneration variable values to external file
  200  if(irun .eq. 1) then
           write(12,1000) duff,totsla,fnjsum,(sregen(i),i=1,ns),cones
 1000      format(20f8.2)
      endif
      return
      END
      SUBROUTINE brnoff(ln,dn,wood)
C ...................................................................
C     compute litter and duff and woody fuel burnoff on stand       .
C     based on equations in Brown and others (1985).                .
C     All litter is burned off and then fractions of duff, and the  .
C     three fuel types are also burned off.                         .
C     all loadings in units of kilograms per square meters          .
C     wood(3)...... kg/m2 for each fuel type 1,10,100 hr.           .
C     dn(k) ....... biomass loading of k'th duff component          .
C     ln(k) ....... biomass loading of k'th litter component        .
C     pduff........ fract by which amount of duff decreases         .
C ...................................................................
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      common/polut/ndyr(7),dmoist
      real ln(1),dn(1),pduff,wood(3)
      integer clrcut
      data da/83.70/,db/-0.426/

C...................
C     compute total loading and average moisture content
C...................
      pduff = (da+db*dmoist*100.0)/100.0
      if(pduff .lt. 0.0) pduff = 0.0
      do 10 i = 1,ns
           ln(i) = 0.0
           dn(i) = dn(i)*pduff
   10 continue
C.....................
C  calculation of woody fuel reductions from brown et al equations
C.....................
      do 20 i = 1,3
           if(i .le. 2) then
                conwood = 0.890 * wood(i)
```

```
          else
               conwood = 0.845 * wood(i)
          endif
          if(conwood .lt. 0.0) conwood = 0.0
          wood(i) = wood(i) - conwood
   20 continue
      return
      END
      SUBROUTINE brush(dbh,ntrees,bbm1,bbm2,init)
C ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C This subroutine computes shrub and herbaceous fuel loadings    :
C for the simulation plot.  The carrying capacity formula uses:  :
C x01,x1,x02,x2 indicate live brushy fuel both tol and intol     :
C g01,g1,g02,g2 indicate live grass and forb fuel both tol-intol :
C b,dd,a,cc are coefficients to the biomass equation.
C ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      common/leaf/aside(7),c(7),alpha(7),b2(7),b3(7),cext(8),crat(7),
     &            sigma(7),ap(7),betap(7)
      common/plotq/elev,rock,till,soilm,text,excess,pltsiz,ifg
      common/trunk/g(7),agemx(7),dm(7),hm(7),spm(8),ysc(7)
      common/hdata/phi,xmbar(8),degd,ainc(7),binfest(8),ibcycle(8),brr
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      integer clrcut
      dimension ntrees(1),dbh(1),b(8),dd(8)
      integer yes,no
      data yes/1/,no/0/
      data b /0.02700,0.04600,0.08605,0.07600,0.06900,0.07000,
     &        0.01598,0.05437/
      data dd /0.02934,0.1190,0.04816,0.04300,0.10125,0.10143,
     &         0.14224,0.19690/
      data x01,x02,g01,g02 /0.0137,0.0137,0.0010,0.0010/
      data a/1.1398/,cc/10.8644/

C ..... Inline function statements for the carrying capacity formula
      r1(y)= 1.-exp(-2.32*(y-.05+abs(y-.05)))
      r2(y)= 2.24*(1.-exp(-.568*(y-.08+abs(y-.08))))
      delta(y)= y * a * (1.0 - (y/b(ifg)))
      gdelta(y) = y * cc * (1.0 - (y/dd(ifg)))

C ..... Setting initial conditions after a fire of any intensity
      if (init.eq.yes) then
           x1= x1 * (1.0 - sburn)
           x2= x2 * (1.0 - sburn)
           if(x1 .eq. 0.0) x1 = x01
           if(x2 .eq. 0.0) x2 = x02
           g1 = g01
           g2 = g02
      endif
      if (ns.eq.0) return

C ..... Summing up all trees and calculating leaf area index for stand
      sla= 0.
      do 10 k= 1,ns
        kk = k
        nk= ntrees(k)
        if (nk.eq.0) go to 10
        if(kk .eq. 1) then
             jj = 0
        else
             jj= isum(ntrees,kk-1)
```

```
        endif
             call needle(tla,jj,nk,dbh,kk,wgt,pltsiz)
             sla = sla + tla
   10 continue

C ..... Calculating all biomass reduction factors for shading effects
      al= phi*exp(-cext(ifg)*sla)

C ..... Calculating current biomass on the simulation plot
      x1 = x1 + r1(al) * delta(x1)
      x2 = x2 + r2(al) * delta(x2)
      g1 = g1 + r1(al) * gdelta(g1)
      g2 = g2 + r2(al) * gdelta(g2)
      if(g1 .gt. dd(ifg)) g1 = dd(ifg)
      if(g2 .gt. dd(ifg)) g2 = dd(ifg)
      bbm1= (x1+x2)/2.
      bbm2= (g1+g2)/2.
      init= no
      return
      END
      SUBROUTINE calcnt
C ***********************************************************************
C * Subroutine calcnt calculates all parameters for growth equation  *
C * from data in external file TREE.DAT.  Intermediate values are    *
C * first calculated based on maximum height, age, and diameter.     *
C * Calculated parameters are then printed in external file OUTPUT.  *
C ***********************************************************************

      common/leaf/aside(7),c(7),alpha(7),b2(7),b3(7),cext(8),crat(7),
     &            sigma(7),ap(7),betap(7)
      common/trunk/g(7),agemx(7),dm(7),hm(7),spm(8),ysc(7)
      common/plotq/elev,rock,till,soilm,text,excess,pltsiz,ifg
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      integer clrcut
      character name*10

C ..... Calculation of intermediate terms in growth equation
      do 10 j=1,ns
           a= 1.-137./hm(j)
           term1= alog(2.*(2.*dm(j)-1.))
           term2= (a/2.)*alog((9./4.+a/2.)/(4.*dm(j)**2+2.*a*dm(j)-a))
           term3= (a+a**2/2.)/sqrt(a**2+4.*a)
           term4= 3.+a-sqrt(a**2+4.*a)
           term5= 4.*dm(j)+a+sqrt(a**2+4.*a)
           term6= 4.*dm(j)+a-sqrt(a**2+4.*a)
           term7= 4.*hm(j)/agemx(j)
           term8= 3.+a+sqrt(a**2+4.*a)
           g(j)= term7*(term1+term2-term3*alog((term4*term5)/
     1          (term6*term8)))
           b2(j)= 2.*(hm(j)-137.)/dm(j)
           b3(j)= (hm(j)-137.)/dm(j)**2
   10 continue

C ..... Writing intermediate results to external files
      write(5,1000)
      name= 'g         '
      write(5,2000) name, (g(j),j=1,ns)
      name= 'b2        '
      write(5,2000) name, (b2(j),j=1,ns)
      name= 'b3        '
```

```
      write(5,2000) name, (b3(j),j=1,ns)
      name= 'c         '
      write(5,3000) name, (c(j),j=1,ns)
      return

C ######################## FORMATS ########################
 1000 format(/1h ,32x,'*derived constants*',/)
 2000 format(1h ,a10,7f10.3)
 3000 format(1h ,a10,7f10.7)
      END
      SUBROUTINE cntrl(dsize,dimax,dimin)
C ***************************************************************************
C  This subroutine:                                                         *
C     reads operating parameters and initial distribution of tree diameters. *
C  Variables are:                                                           *
C     nsum......... total number of trees initially on the stand            *
C     nspan........ number of years per run of the model                    *
C     nruns........ number of runs of the model                             *
C     nbins........ number of diameter cohorts for inital state             *
C     width........ width in cm for each diameter cohort                    *
C     dbh0(j)...... vector of initial tree diameters in cm                  *
C     ntrees0(j)... number of trees initially in the j'th species           *
C     ncount(i,j).. number trees init in i'th diam cohort for j'th species  *
C ***************************************************************************
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      common/init/ ntrees0(7),dbh0(4000),ncount(20,7),nbins,width
     1  ,age0(4000),agein(20,7)
      common/limits/ mxtrs,maxspc,mxdd,mxyrs,maxbin
      real dsize(7)
      integer clrcut,yes,agein
      character*10 name
      data yes/1/

      open(unit=4,file='CONTRL.DAT',form='formatted',recl=150,
     &     pad='yes')

C ..... Reading in simulation specifics, then writing the input to file
      read(4,1000)  name,nspan
      write(5,1000) name,nspan
      read(4,1000)  name,nruns
      write(5,1000) name,nruns
      read(4,1000)  name,clrcut,dimax,dimin
      write(5,1000) name,clrcut,dimax,dimin
      read(4,1000)  name,ifire
      write(5,1000) name,ifire
      read(4,1000)  name,ibr
      write(5,1000) name,ibr
      read(4,1000)  name,impb
      write(5,1000) name,impb
      read (4,4000) name,(dsize(j),j=1,ns)
      write(5,4000) name,(dsize(j),j=1,ns)
      read(4,1000)  name,nwrstr
      write(5,1000) name,nwrstr
      read(4,1000)  name,nbins
      write(5,1000) name,nbins
      read(4,2000)  name,width
      write(5,2000) name,width
C     if (nbins.gt.maxbin) call error(4)
C     if (nspan.gt.mxyrs)  call error(5)
      do 10 i= 1,nbins
```

```
          read(4,3000)  name,(ncount(i,j),j=1,ns)
          write(5,3000) name,(ncount(i,j),j=1,ns)
   10 continue
        do 20 i=1,nbins
            read(4,3000) name, (agein(i,j),j=1,ns)
            write(5,3000)name, (agein(i,j),j=1,ns)
   20   continue
      nsum= 0
      do 30 i= 1,nbins
          do 40 j= 1,ns
              nsum= nsum+ncount(i,j)
   40     continue
   30 continue
      if (nsum.gt.mxtrs) call error(6)
      rewind 4
      close(4)
      return

C ####################### Formats #######################
 1000 format(a10,i6,f10.2,f10.2)
 2000 format(a10,f6.1)
 3000 format(a10,7i6)
 4000 format(a10,7f7.1)
      END
      SUBROUTINE crown(ntrees,dbh,ros,byram,flame,fzone,icwf)
      dimension dbh(1),ntrees(1)
        icwf = 0
        return
      END
      SUBROUTINE cycles(x,n,m,u,p,r)
C ***************************************************************************
C This subroutine assigns cone crop years from species-specific prob-      *
C  abilities for having a good cone crop.  A uniform random number gen-    *
C  erator is used (XRANDOM)  and is called from subroutine RGEN.           *
C Variables used:                                                          *
C     X(i,j): binary array storing appropriate classes of cone crops       *
C     P(i): probability of a good cone crop for species i.                 *
C     R(i): number of years to block after a good cone crop for spp i.     *
C     U(i): temporary storage array.                                       *
C ***************************************************************************
      integer x(n,m),r(7)
      real u(1),ul(1),p(7)
      if (n.eq.0.or.m.eq.0) return

C ..... Initializing cone crop array
      do 10 i= 1,n
        do 20 j= 1,m
          x(i,j)= 0
   20   continue
   10 continue

C ..... Calculating probabilities for blocked and unblocked states
      do 50 j= 1,m
          i= 0
          if (r(j).eq.1) go to 30

C ..... Calculate pnb, prob of an ublocked state
          pnb= 1./(p(j)*float(r(j)-1))
          call rgen(ul,1)
          if (ul(1).le.pnb) go to 30
```

```
C ..... Select an integer b at random from 1,2,3,... r-1
            call rgen(ul,1)
            i= int(float(r(j)-1)*ul(1))+1
   30       call rgen(u,n)
   40       i= i+1
            if (i.gt.n) go to 50
            if (u(i).gt.p(j)) go to 40
            x(i,j)= 1
            i= i+r(j)-1
            go to 40
   50  continue
       return
       END
       SUBROUTINE dist(u,itop)
C ****************************************************************************
C  This subroutine calculates initial distribution of tree diameters.        *
C   - if clearcut option is specified set inital diameter vector to zero.    *
C      Trees are distributed randomly (ie. uniform pdf) within a diam cohort *
C      Variables are:                                                        *
C       nbins........ number of diameter cohorts for inital state            *
C       width........ width in cm for each diameter cohort                   *
C       dbh0(j)...... vector of initial tree diameters in cm                 *
C       ntrees0(j)... number of trees initially in the j'th species          *
C       ncount(i,j).. number trees init in i'th diam cohort, j'th species    *
C       clrcut....... flag to specify clear cut option                       *
C ****************************************************************************
       common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
       common/init/ ntrees0(7),dbh0(4000),ncount(20,7),nbins,width,
     &             age0(4000),agein(20,7)
       common/limits/ mxtrs,maxspc,mxdd,mxyrs,maxbin
       integer clrcut,yes,agein
       dimension u(1),itop(1)
       data yes/1/

C ..... Initialize appropriate arrays
       do 5 i= 1,ns
            ntrees0(i)= 0
    5  continue

       do 8 i= 1,mxtrs
            dbh0(i)= 0.0
            age0(i)= 0.0
            itop(i) = 0
    8  continue

C ..... Assign each tree diameter and age to appropriate cell in each
C .....  array (DBH and AGE)
       kk= 0
       do 10 j= 1,ns
         do 20 i= 1,nbins
              n= ncount(i,j)
              ntrees0(j)= ntrees0(j)+n
              if (n.eq.0) go to 20
              call rgen(u,n)
              do 30 k= 1,n
                   dbh0(kk+k)= width*(u(k)+i-1)
                   age0(kk+k)= float(agein(i,j))
   30         continue
              kk= kk+n
```

```
   20   continue
   10 continue
      return
      END
      SUBROUTINE error(fmt)
C ***************************************************************************
C  This subroutine terminates program and send message to terminal.       *
C ***************************************************************************
      integer fmt
      character*50 msg(12)
      data msg /' N1 is greater than N2 .                           ',
     1         ' N1 is greater than MID.                           ',
     2         ' MID is greater than N2.                           ',
     3         ' Too many diameter cohorts.                        ',
     4         ' Time span is too large, redo control file.        ',
     5         ' Initial distribution has too many trees.          ',
     6         ' Too many species in TREDAT, redo file.            ',
     7         ' No end-of-species marker, fix TREDAT file.        ',
     8         ' Too many trees in BIRTH.                          ',
     9         ' Too many dead trees in KILL.                      ',
     1         ' DINC is greater than 5.0 cm, abnormal.            ',
     2         '                                                   '/

C ..... Print appropriate error message
      write(5,1000) msg(fmt)
 1000 format(/1H ,a50)
      stop
      END
      SUBROUTINE fire(ntrees,dbh,fwg,nl,p,yr,duff,branch,wood,
     &                irun,icwf,dimax,dimin)
C *****************************************************************************
C This subroutine is a sub-driver for all components used to calculate fire *
C   intensity.  Subroutine logic is as follows:                              *
C     1.  Update fuel loadings: call subroutine FUEL                         *
C     2.  Compute if current simulation year is a fire year, if not RETURN   *
C     3.  Assign fuel loadings into appropriate array TFWG(i,j).             *
C     4.  Compute fire intensity: call FIREMOD.                              *
C     5.  Compute scorch height and resultant tree mortality: call INJURY    *
C     6.  Compute fuel comsumption: call BRNOFF                              *
C     7.  Compute duff and litter depth.                                     *
C   Important variables are:                                                 *
C     TFWG(i,j)- fuel loadings for live and dead fuel components,            *
C     DUFF- duff and litter depth in cms,                                    *
C   Computed intensity and scorch height are written to external file.        *
C *****************************************************************************
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      common/leaf/aside(7),c(7),alpha(7),b2(7),b3(7),cext(8),crat(7),
     &            sigma(7),ap(7),betap(7)
      common/plotq/elev,rock,till,soilm,text,excess,pltsiz,ifg
      common/polut/ndyr(7),dmoist
      common/birthk/sura(7),surb(7),dbulk(8,2),disequ(2,7),rdelay(8)
      common/sites/ occur(500),rh,wind,ttheta,t
      common/fuel1/ mext(2),rhop(2,7),tbulk(2,8),mois(2,7)
      common/fuel2/ mps(2,7),lhv(2,7),st(2,7),se(2,7)
      common/fuel5/ amc(7),bmc(7),cmc(7),dmc(7),mmc(7),tmc,emc(7)
      common/mort/ d1(7),d2(7),d3(7),bc(7)
      dimension ntrees(1),dbh(1),p(1),fwg(2,7),tfwg(2,7)
      real ln(7),ln1(7),dn(7),dn1(7),wood(3),lw,mois,hs
      integer flag(3),yr,yes,no,occur,clrcut
      data yes/1/,no/0/
```

```
      data lnl/7*0./,dnl/7*0./
      data init/1/

C ..... Initialization of parameters
      icwf = 0
      duff1 = 0.0
      duff2 = 0.0
      lw = 0.0
      n= isum(ntrees,ns)
      if (n.eq.0) return

C ..... Decide if current year is a clearcut year
      if(clrcut .eq. yr) then
           do 10 i = 1,n
                if(dbh(i) .ge. dimin .and. dbh(i) .le. dimax) then
                     p(i) = 0.99999
                endif
   10      continue
           go to 30
      endif

C ..... Update fuel components, including litter and duff.
      call fuel(ntrees,dbh,fwg,ln,lnl,dn,dnl,wood,yr,init,irun,
     &          branch,icwf)

C ..... Decide if current year is a fire year.
      if (occur(yr).eq.no) go to 30

C ..... Putting the five dead fuel types into temporary array
C .....  tfwg(i,j) types are litter, 1 hour, 10, and 100 hour woody,
C .....  and cured grass and last dead shrub.
      do 15 i = 1,ns
           lw = lw + ln(i)
           tfwg(1,i) = 0.0
   15 continue
      tfwg(1,1) = lw
      do 16 i = 1,3
           tfwg(1,i+1) = wood(i)
   16 continue
      tfwg(1,5) = fwg(1,5)
      tfwg(1,6) = fwg(1,6)
      tfwg(1,7) = 0.0
      do 17 i = 1,2
           tfwg(2,i) = fwg(2,i)
   17 continue

C ..... Simulating a fire by calling FIREMOD
      call firemd(nl,tfwg,byram,flag,ifg,rate,flame,fzone)

C ..... Computing crown fire initiation
      call crown(ntrees,dbh,rate,byram,flame,fzone,icwf)

C ..... Calculating scorch height and tree mortality
      call injury(ntrees,dbh,byram,p,hs,icwf)

C ..... Computing fuel reduction or consumption
      call brnoff(ln,dn,wood)
      init= yes

C ..... Writing fire intensity and scorch height to file
```

```
      if(irun .eq. 1) then
           write(11,1000) yr,byram,hs,flame,rate
 1000      format(I4,7f10.4)
      endif

C ..... Calculating the depth of the duff layer from duff and litter
C ..... components LN and DN.

   30 do 40 i=1,ns
           duff1 = duff1 + ln(i)
           duff2 = duff2 + dn(i)
   40 continue
C ..... Computation of duff depth from duff bulk density
      duff1 =  (duff1/dbulk(ifg,1))*100.0
      duff2 =  (duff2/dbulk(ifg,2))*100.0
      duff = duff1 + duff2
      return
      END
      SUBROUTINE firemd(nl,fwg,byram,flag,ifg,rate,flame,fzone)
C     ****************************************************************
C     *                                                              *
C     *   metric version of original (nov. 1973) SUBROUTINE firemd   *
C     *   -- units are converted on input and reconverted on output  *
C     *   but internal computation is expressed in british units --  *
C     *                                                              *
C     *   conversion factors are stored in array named  * cio *      *
C     *   factor      value      converts      from       to         *
C     *   ......      .......    ........      ....       ....       *
C     *   cio(1)     .032808      sigma        1/ft       1/cm       *
C     *   cio(2)     .18915     xir,ir,xio  btu/sqft/min kw/sqm      *
C     *   cio(3)     37.259       rhobqig     btu/cuft   kj/cu m     *
C     *   cio(4)     1.60934      wind....      mi/h       km/h      *
C     *   cio(5)     .3048      ratex,rate     ft/min     m/min      *
C     *   cio(6)     3.4592     byramx,byram  btu/ft/s    kw/m       *
C     *   cio(7)     4.8824        fwg        lb/sq ft   kg/sq m     *
C     *   cio(8)     2.3244        lhv         btu/lb     kj/kg      *
C     *   cio(9)     .016018       rhop       lb/cu ft    g/cc       *
C     *                                                              *
C     *                                                              *
C     *   variables used in this SUBROUTINE (written in fortran - iv) *
C     *   are identified below. the rate-of-spread model employed is *
C     *   documented in usda forest service research paper int-115,  *
C     *   a mathematical model for predicting fire spread in wildland *
C     *   fuels, r. rothermel (northern forest fire lab., missoula), *
C     *   but excluding the **effective heating number** revision of *
C     *   w.h. frandsen suggested in usda forest service general tech- *
C     *   nical report int-10, 1973. the calculation of byrams inten- *
C     *   sity (btu/min/ft of fireline length) is based on the crude *
C     *   approximation that the burning zone produces a uniform rate *
C     *   of heat output from front to back and that the depth of the *
C     *   flame is determined by the burning time of the gross descrip-*
C     *   tive mean particle diameter 4/sigma.                       *
C     *   significant revisions include.....                         *
C     *       a new way of computing the moisture of extinction of   *
C     *       live fuels, including 1) exponential weighting of size *
C     *       classes to get fine dead/live ratio and 2) using mext(1) *
C     *       in place of the constant 0.3 in the equation for mext(2) *
C     *       use of a new weighting factor, g(i,j), in place of     *
C     *       f(i,j) in computing net effective loading by size class *
```

```
C     *       use of a power law formula for the reaction velocity      *
C     *       correlation parameter *a*                                 *
C     *       elimination of weighting factors on reaction intensity   *
C     *       of categories  (eff. heating no. or f(i) )                *
C     *   programmed nov. 1973 by f. albini, nffl, missoula.            *
C     *                                                                 *
C     *   input variables...first the physical variables                *
C     *                                                                 *
C     *   symbol    pg.no./eq.no.            definition                 *
C     *             in int-115                                          *
C     *   mext(1)...31/65         moisture of extinction of dead fuel *
C     *   ttheta....33/80         tangent of local slope                *
C     *   mois(i,j).31/66         moisture content of fuel type (i,j) *
C     *   mps(i,j)..30/53,32/72   mean surf/vol, 1/ft, of fuel (i,j)  *
C     *   fwg(i,j)..31/60,32/73,74 surface loading, lb/sqft fuel (i,j) *
C     *   lhv(i,j)..31/61         low heat value, btu/lb, fuel (i,j)  *
C     *   rhop(i,j).30/53,32/73   ovendry particle density, lb/cuft   *
C     *   st(i,j)...31/60         mineral content of fuel type (i,j)  *
C     *   se(i,j)...31/63         mineral content excluding silica    *
C     *   wind....                wind speed at mid flame height (mph)*
C     *                                                                 *
C     *   input variables...program control and specification variables*
C     *                                                                 *
C     *   symbol    size range              description                 *
C     *                                                                 *
C     *   nd........ 0 - 7    number of dead fuel size classes to be   *
C     *                       considered (specifies largest class if   *
C     *                       there are more classes than nd)          *
C     *   nl........ 0 - 7    same as nd, but for live fuels           *
C     *   ifines(1). 1 - nd   ordinal number of smallest-size dead fuel*
C     *                       to be used in computation                *
C     *   ifines(2). 1 - nl   same as ifines(1) but for live fuels     *
C     *  large1    largest dead fuel size class to be included         *
C     *  large2    largest live fuel size class to be included         *
C     *                                                                 *
C     *                                                                 *
C     *                 .....output variables.....                      *
C     *                                                                 *
C     *                                                                 *
C     *   symbol                        definition                      *
C     *                                                                 *
C     *   flag( ) . array of error flags,set to 1 for error            *
C     *             flag(1) dead fuel too moist too spread flame       *
C     *             flag(2) wind speed exceeds reliable extrapolation  *
C     *             flag(3) gross surf/vol too small (sigma.lt.175)    *
C     *   betal.....mean packing ratio (pg 32/eq 73)                   *
C     *   sigma.....characteristic surface area to volume ratio of the *
C     *             fuel complex, 1/ft (pg 32/eq 71)                   *
C     *   gamma.....reaction velocity, 1/min (pg 31/eq 67)             *
C     *   xir.......reaction intensity, btu/min/sqft, calculated from  *
C     *             eq 58, pg 31, but with area-weighting factor, f-sub*
C     *             -i replaced by unity....no category weighting      *
C     *   rhobqig...heat sink term -product of bulk density, effective *
C     *             heating number, and heat of preignition- btu/cuft  *
C     *             (pg 32/eq 77)                                      *
C     *   phis......slope factor modifying spread rate (pg 33/eq 80)   *
C     *   windx.....wind speed which produces maximum spread rate, mph *
C     *             (pg 33/eq 86)                                      *
C     *   phiwx.....maximum value of wind factor (pg 33/eq 80,87)      *
C     *   ratex.....maximum wind-driven rate of spread, ft/min (pg 32/ *
```

```
C     *            eq 75, with phi-sub-w of eq 79 at u=0.9*i-sub-r)   *
C     *   byramx....byrams intensity, btu/min/ft of fireline length,   *
C     *            at the rate of spread = ratex (near statement 30)  *
C     *   ir(i).....reaction intensity, btu/min/sqft, for dead (i=1)   *
C     *            or live (i=2) fuel type -components of xir         *
C     *   mext(2)...moisture of extinction of live fuel (pg 35/eq 88)  *
C     *   **n.b.- mext(1), for dead fuel, is an input parameter        *
C     *   byram.....byrams intensity, btu/min/ft of fireline length,   *
C     *            for wind speed corresponding to index j (near 33)  *
C     *   rate......spread rate, ft/min, for wind speed (pg 32/eq 75)  *
C     *   flame ....flame lenght in meters p86, eq 17
C     *                                                                *
C     *   working variables....internal to SUBROUTINE                  *
C     *      -index i refers to fuel category (1=dead, 2=live)         *
C     *      -index j refers to (size) class within category (j.le.100)*
C     *                                                                *
C     *   symbol                        definition                     *
C     *                                                                *
C     *   ai(i).....fuel surface area/sqft of ground (pg 30/eq 54)     *
C     *   a(i,j)....fuel surface area/sqft of ground (pg 30/eq 53)     *
C     *   wo(i,j)...net dry fuel loading, lb/sqft (pg 31/eq 60)        *
C     *   f(i,j)....weighting factor (pg 30/eq 56)                     *
C     *   g(i,j)....weighting factor for computing net effective load- *
C     *            ing for each category...replaces weighting factor  *
C     *            f(i,j) used for intrinsic properties (pg 30/eq 56) *
C     *            for loading calculation, size classes are grouped  *
C     *            and weighted uniformly according to contribution to*
C     *            total area by group as a whole...g = aa(n)/ai(i).. *
C     *   aa1.......area of size class 1 (mps.ge.1200)                 *
C     *   aa2.......area of size class 2 (1200.gt.mps.ge.192)          *
C     *   aa3.......area of size class 3 (192.gt.mps.ge.96)            *
C     *   aa4.......area of size class 4 (96.gt.mps.ge.48)             *
C     *   aa5.......area of size class 5 (48.gt.mps.ge.16)             *
C     *   ..........note - fuels with mps .lt. 16 are not used         *
C     *   gs(i,j)...shorthand for exp(-138./mps(i,j))                  *
C     *   at........total fuel surface area/sqft of ground (pg 30/eq55)*
C     *   fx(i).....weighting factor (pg 30/eq 57)                     *
C     *   noclas(i).noclas(1)=nd, noclas(2)=nl. see inputs             *
C     *   isize(i,j)=place no. of jth finest fuel, category i          *
C     *   fined.....dry loading of dead fines, lb/sqft                 *
C     *   finel.....dry loading of live fines, lb/sqft                 *
C     *   wdfmn.....total moisture loading of dead fines, lb/sqft      *
C     *   findm.....average moisture of dead fines (wdfmn/fined)       *
C     *   xmoisl....computed live moisture of extinction (pg 35/eq 88) *
C     *   ax........=f(i,j)                                            *
C     *   qig(i,j)..heat of preignition, btu/lb (pg 32/eq 78)          *
C     *   mcsa(i)...weighted average moisture content (pg 31/eq 66)    *
C     *   bse(i)....weighted average mineral content (pg 31/eq 63)     *
C     *   sigmal(i).characteristic surf/vol ratio (pg 32/eq 72)        *
C     *   lhvl(i)...weighted average low heat value, btu/lb (pg31/eq61)*
C     *   suml......total dry loading, lb/sqft -(see pg 32/eq 74)      *
C     *   sum2......total volumetric loading, ft (see pg 32/eq 73)     *
C     *   wol(i)....weighted average fuel loading, lb/sqft (pg 31/eq59)*
C     *   sum3......sum in heat sink equation, btu/cuft (pg 32/eq 77)  *
C     *   beta......moisture content/moisture of extinction...redefined*
C     *            for each category (pg 31/eq 65)                    *
C     *   mdcsa(i)..moisture damping coefficient (pg 31/eq 64)         *
C     *   barns(i)..mineral damping coefficient (pg 31/eq 64)          *
C     *   sigma.....gross characteristic surf/vol ratio (pg 32/eq 71)  *
C     *   rhopl.....bulk density of fuel complex, lb/cuft (pg 32/eq 74)*
```

```
C     *   best......computed optimum packing ratio (pg 32/eq 69)        *
C     *   rat.......ratio of packing ratio to best (used in eq 67/pg31)*
C     *   al........empirical fit parameter a of eq 70/pg 32            *
C     *             but nondivergent power law used, not eq 70/pg 32    *
C     *   v.........sigma**1.5 used in eq 68/pg 32                      *
C     *   b.........exponent in eqn for propagating flux/reaction in-   *
C     *             tensity, xsi, (pg 32/eq 76)                         *
C     *   xml.......parameter b of eq 83/pg 33                          *
C     *   xnl.......parameter e of eq 84/pg 33                          *
C     *   cl........parameter c of eq 82/pg 33                          *
C     *   wmax......maximum effective wind speed, ft/min (pg 33/eq 86) *
C     *   r.........rate of spread, ft/min (pg 32/eq 75)                *
C     *   rmax......maximum wind-driven rate of spread, ft/min          *
C     *                                                                 *
C     **********     firemd     ************      firemd    **********
      common/fuel1/ mext(2),rhop(2,7),tbulk(2,8),mois(2,7)
      common/fuel2/ mps(2,7),lhv(2,7),st(2,7),se(2,7)
      common/sites/ occur(500),rh,wind,ttheta,t
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      real rhop,mext,mois,mps,lhv,st,se,wind,ttheta
      dimension ai(2),bse(2),sigmal(2),wol(2),
     &         a(2,7),f(2,7),fx(2),wo(2,7),qig(2,7),barns(2)
      real betal,sigma,gamma,xir,rhobqig,phis,windx,phiwx,ratex,
     &    lhvl(2)
      real byramx,byram,rate,xio,fwg(2,7),mcsa(2),mdcsa(2),ir(2)
      integer isize(2,7),ifines(2),large1,large2,nl,nd,flag(3),clrcut
      dimension g(2,7),gs(2,7),gn(2),noclas(2),cio(9),
     &         bulk(2,7)
      data cio/.032808,.18915,37.259,1.60934,.3048,3.4592,4.8824,
     &        2.3244,0.016018/

      nd = 6
      large1= nd
      large2= nl
      ifines(1)= 1
      ifines(2)= 1
      do 651 i=1,nl
           do 650 j=1,nd
                mps(i,j)=mps(i,j)/cio(1)
                fwg(i,j)=fwg(i,j)/cio(7)
                lhv(i,j)=lhv(i,j)/cio(8)
                rhop(i,j)=rhop(i,j)/cio(9)
                if(i .eq. 1) bulk(i,j)= tbulk(i,ifg)/cio(9)
                if(i .eq. 2) bulk(i,j) = tbulk(i,j)/cio(9)
 650       continue
 651  continue
      wind = wind/cio(4)
      noclas(1) = nd
      noclas(2) = nl
C.... zero all working arrays and initialize variables
      gamma=0.
      xir=0.
      windx=0.
      phiwx=0.
      ratex=0.
      byramx=0.
      xio=0.
      flag(1)= 0
      flag(2)= 0
      flag(3)= 0
```

```
      mext(2)= 0.
      do 1 i=1,2
           ai(i)=0.
           mcsa(i)=0.
           bse(i)=0.
           sigmal(i)=0.
           lhvl(i)=0.
           wol(i)=0.
           sum4= 0.
           suml= 0.
           sum2= 0.
           sum3= 0.
           ir(i)= 0.
           barns(i)= 0.
           fx(i)= 0.
           sigma= 0.
           at= 0.
           gn(i) = 0.
           do 1 j=1,7
                isize(i,j)=j
                g(i,j) =0.
                gs(i,j) = 0.
                a(i,j)=0.
                f(i,j)=0.
                wo(i,j)=0.
                qig(i,j)=0.
                byram=0.
                rate =0.
    1 continue
C     sort fuel components by size, finest fuels first
C     isize(i,j) = place no. of jth finest fuel of category i
      do 4 i=1,2
           jmax = noclas(i)
           if(jmax.le.1) go to 4
           jmm = jmax -1
           do 3 j = 1,jmm
                km = jmax - j
                do 2 k=1,km
                     ida=isize(i,k)
                     idb=isize(i,k+1)
                     siza=mps(i,ida)
                     sizb=mps(i,idb)
                     if(siza.ge.sizb) go to 2
                     isize(i,k+1)=ida
                     isize(i,k)=idb
    2           continue
    3      continue
    4 continue
C     delete large logs from firespread considerations
      do 205 i = 1,2
           kmax = noclas(i)
           if(kmax.lt.1) go to 205
           do 202 k = 1,kmax
                j = isize(i,k)
                if((mps(i,j)).ge.16.) go to 202
                noclas(i) = k-1
                go to 205
  202      continue
  205 continue
C     calculate weighting factors
```

```
C     first, for dead fuels....
C     then for live fuels....
      n1 = noclas(1)
      n2 = noclas(2)
      noclas(1) = min0(large1,n1)
      noclas(2) = min0(large2,n2)
      do 7 i = 1,2
           kmin = ifines(i)
           kmax = noclas(i)
           if((kmax.eq.0).or.(kmin.gt.kmax))  go to 7
           do 5 k = kmin,kmax
                j = isize(i,k)
                gs(i,j) = mps(i,j)/rhop(i,j)
                a(i,j) = fwg(i,j)*gs(i,j)
                gs(i,j) = exp(-138./mps(i,j))
                ai(i) = ai(i) + a(i,j)
                wo(i,j) = fwg(i,j)*(1. - st(i,j))
    5      continue
           do 6 k = kmin,kmax
                j = isize(i,k)
                f(i,j) = a(i,j)/ai(i)
    6      continue
    7 continue
      at = ai(1) + ai(2)
      fx(1) = ai(1)/at
      fx(2) = 1. - fx(1)
C.... find weight loading of dead and live fines, moisture extinct. live
C.... note dead and live fuels wtd by exp(-c/sigma) -- c=138 or 500
      fined= 0.0
      finel= 0.0
      wdfmn= 0.0
      findm= 0.0
      do 18 i=1,2
            n=ifines(i)
            jm=noclas(i)
            if((jm.le.0).or.(n.gt.jm))  go to 18
            if(i.eq.2)  go to 15
            do 13 j=n,jm
                jj=isize(i,j)
                sa=mps(i,jj)
                ep =exp(-138./sa)
                wtfac= fwg(i,jj)*ep
                wmfac= wtfac*mois(i,jj)
                fined =fined + wtfac
                wdfmn = wdfmn + wmfac
   13      continue
           if(fined.eq.0.) go to 18
           findm = wdfmn/fined
   15      if(i.eq.1) go to 18
           do 16 j=n,jm
                jj = isize(i,j)
                sa = mps(i,jj)
                ep = exp(-500./sa)
   16           finel = finel + fwg(i,jj)*ep
   18 continue
      if(finel.eq.0.) go to 19
      factor = fined/finel
      xmoisl=2.9*factor*(1.-findm/mext(1))-0.226
      if(xmoisl.lt.mext(1))  xmoisl=mext(1)
      go to 20
```

```
 19  xmoisl=100.
 20  mext(2)=xmoisl
C.... intermediate computations for each category of fuel (live + dead)
     do 22 i=1,2
     aa1 = 0.0
     aa2 = 0.0
     aa3 = 0.0
     aa4 = 0.0
     aa5 = 0.0
     jm=noclas(i)
       n=ifines(i)
     if((jm.eq.0).or.(n.gt.jm)) go to 22
     do 21 k=n,jm
     j=isize(i,k)
       ax=f(i,j)
     sigm = mps(i,j)
     if(sigm.ge.1200.) aa1 = aa1 + a(i,j)
     if((sigm.lt.1200.).and.(sigm.ge.192.)) aa2 = aa2 + a(i,j)
     if((sigm.lt.192.).and.(sigm.ge.96.)) aa3 = aa3 + a(i,j)
     if((sigm.lt.96.).and.(sigm.ge.48.)) aa4 = aa4 + a(i,j)
     if(sigm.lt.48.) aa5 = aa5 + a(i,j)
     qig(i,j)=250. + 1116.*mois(i,j)
     mcsa(i)=mcsa(i) + ax*mois(i,j)
     bse(i)=bse(i) + ax*se(i,j)
     sigmal(i)=sigmal(i) + ax*mps(i,j)
     lhvl(i)=lhvl(i) + ax*lhv(i,j)
     sum4= sum4+bulk(i,j)*fwg(i,j)
     sum1=sum1 + fwg(i,j)
     sum2=sum2 + fwg(i,j)/rhop(i,j)
 21  sum3  =  sum3 + fx(i)*f(i,j)*qig(i,j)*gs(i,j)
     do 221 k = n,jm
     j = isize(i,k)
       sigm = mps(i,j)
     if(sigm.ge.1200.) g(i,j) = aa1/ai(i)
     if((sigm.lt.1200.).and.(sigm.ge.192.)) g(i,j) = aa2/ai(i)
     if((sigm.lt.192.).and.(sigm.ge.96.)) g(i,j) = aa3/ai(i)
     if((sigm.lt.96.).and.(sigm.ge.48.)) g(i,j) = aa4/ai(i)
     if(sigm.lt.48.) g(i,j) = aa5/ai(i)
     wol(i) = wol(i) + g(i,j)*wo(i,j)
 221 continue
     beta = mcsa(i)/mext(i)
     mdcsa(i)=1. - beta*(2.59 - beta*(5.11 - beta*3.52))
     if(mext(i).lt.mcsa(i)) mdcsa(i)=0.
     barns(i)=0.174/(bse(i)**0.19)
     if(barns(i).gt.1.) barns(i)=1.
     sigma=sigma + fx(i)*sigmal(i)
     ir(i) = wol(i)*lhvl(i)*mdcsa(i)*barns(i)
 22  continue
     if (mdcsa(1).le.0) flag(1)= 1
     if (mdcsa(1).le.0.) go to 3777

C.... begin final computations
C.... bulk density....
     rhopl= sum4/sum1

C.... packing ratio
     betal= sum2*rhopl/sum1

C.... optimum packing ratio
     best=3.348/(sigma**.8189)
```

```
      rat=betal/best

C.... new exponent a equation used here
      al=133./(sigma**.7913)

C.... reaction intensity weighted by surface area fraction
      v=sigma**1.5
      gamma=(v*(rat**al)*exp(al*(1.-rat)))/(495. + .0594*v)
      ir(1)=gamma*ir(1)
      ir(2)=gamma*ir(2)
      xir=ir(1)+ir(2)
C.... heat sink terms
      rhobqig=rhopl*sum3
C.... propagating intensity
      b= (.792+.681*sqrt(sigma))*(.1+betal)
      xio =(xir*exp(b))/(192. + .2595*sigma)
C.... slope factor phis
      phis=5.275*ttheta*ttheta/(betal**0.3)
C.... parameters for determining wind factor phiw
      xml=0.02526*(sigma**.54)
      xnl=0.715*exp(-0.000359*sigma)
      cl =7.47*exp(-0.133*(sigma**.55))
      cl = cl/(rat**xnl)
      wmax=0.9*xir
        windx=wmax/88.
         phiwx=cl*(wmax**xml)
      rmax=xio*(1.0 + phis + phiwx)/rhobqig
        ratex=rmax
      byramx=xir*ratex*384./sigma
      w=wind*88.
        phiw=cl*(w**xml)
         r=xio*(1.+phis+phiw)/rhobqig
      rate= r
      byram= xir*r*384./sigma
      fzone = (byram/xir)
      if((w.ne.0.).and.(sigma.lt.175.))  flag(3)=1.0
      if (w.gt.wmax) flag(2)= 1

C     before return to calling program
C     must convert everything to metric here

 3777 continue
      sigma=sigma*cio(1)
       xir=xir*cio(2)
        rhobqig=rhobqig*cio(3)
      windx=windx*cio(4)
       ratex=ratex*cio(5)
        byramx=byramx*cio(6)/60.
      ir(1)=ir(1)*cio(2)
       ir(2)=ir(2)*cio(2)
      do 3778 i=1,nl
      do 3778 j=1,nd
           mps(i,j)=mps(i,j)*cio(1)
           fwg(i,j)=fwg(i,j)*cio(7)
           lhv(i,j)=lhv(i,j)*cio(8)
           rhop(i,j)=rhop(i,j)*cio(9)
           bulk(i,j)= bulk(i,j)*cio(9)
 3778 continue
      flame = 0.45 * (byram/60.0)**(0.46)
      wind= wind*cio(4)
```

```
      bcio=cio(6)/60.
       rcio=cio(5)
      byram=bcio * byram
      rate= rate * rcio
      flame = flame * cio(5)
      fzone = fzone * cio(5)
      xio=xio*cio(2)
      return
      END
      SUBROUTINE FLTEMP(flame,ftmp)
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C  This subroutine calculates the average flame temperature of a
C  fire with a specified intensity and rate of spread.  This temp
C  is used in the calculation of heat needed to ignite crown.
C ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

       trate = 1500.0 / flame
       if(trate .gt. 1500.0) trate = 1500.0
       ftmp = 2000.0 - (trate)
       return
      END
      SUBROUTINE foil(pfoil,dbh,kk)
C ********************************************************************
C * Subroutine foil calculates the proportion foliage in the live    *
C * crown using regression equations from Brown (1976).  Equations   *
C * are exponential form except for grand fir and lodgepole pine     *
C * crown portion regression equations.                              *
C *   pfoil - proportion of live foliage in crown.
C ********************************************************************
      common/types/ishade(7),imoist(7),spp(7)
      common/leaf/aside(7),c(7),alpha(7),b2(7),b3(7),cext(8),crat(7),
     &            sigma(7),ap(7),betap(7)
      character*1 ishade,imoist,spp*4

C ..... Calculate the pro. foilage for each individual species
          if(spp(kk) .eq. 'abgr') then
               pfoil = 1.0 / (ap(kk) + betap(kk)*dbh)
          elseif(spp(kk) .eq. 'pico') then
               pfoil = ap(kk) + betap(kk)*dbh
          else
               pfoil = ap(kk)*exp(betap(kk)*dbh)
          endif
      return
      END
      SUBROUTINE fuel(ntrees,dbh,fwg,ln,ln1,dn,dn1,wood,yr,init,irun,
     &                branch,icwf)
C ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C This subroutine:                                                        :
C     calculates moisture content and loading for each fuel component     :
C     mois(1,k) ... fraction moist content of fuel component k            :
C     fwg(1,k) .... biomass loading of fuel component k  kg/sq m          :
C     emc(k) ...... equilibrium moisture content in percent               :
C     bbm ......... brush biomass loading, kg/sq m                        :
C     rh .......... relative humidity in percent                          :
C     t ........... ambient temperature in deg c                          :
C ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      common/fuel1/ mext(2),rhop(2,7),bulk(2,8),mois(2,7)
      common/fuel5/ amc(7),bmc(7),cmc(7),dmc(7),mmc(7),tmc,emc(7)
      common/sites/ occur(500),rh,wind,ttheta,t
      common/plotq/elev,rock,till,soilm,text,excess,pltsiz,ifg
```

```
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      common/polut/ndyr(7),dmoist
      integer clrcut,yr
      dimension ntrees(1),dbh(1),fwg(2,7),sfuel(8)
      real ln(1),lnl(1),dn(1),dnl(1),wood(3)
      real mois,mext,branch,amc,bmc,cmc,dmc,mmc,tmc,rh,emc
      data sfuel/1.000,1.000,0.717,0.668,0.768,0.768,0.985,0.852/

      flit = 0.0
      if (ns.le.0) return

C ..... Update fuel loadings
      call loader(ntrees,dbh,lnl,ln,dnl,dn,wood,yr,branch,icwf)

C ..... Calculation of moisture content of fuel - defined as EMC
        do 20 k= 1,ns
             if(emc(k) .eq. 0.0) then
                  emc(k) = amc(k)*rh**bmc(k)+cmc(k)*exp((rh-100.)/
     &                       dmc(k))+mmc(k)*(tmc-t)
             endif
             flit = flit + ln(k)
             mois(1,k)= emc(k)
   20   continue

C ..... Update fuel loadings for shrubby and herbaceous fuels
      call brush(dbh,ntrees,bbml,bbm2,init)

C ##########################################################################
C  Putting shrub and grass fuel in appropriate element of fuel
C  array (fwg).  Proportions sfuel(i) for shrubs go into live
C  fuel, and 0.90 for herbaceous go into dead fuels and vice
C  versa.
C ##########################################################################

      fwg(1,1) = flit
      do 30 i = 1,3
           fwg(1,i+1) = wood(i)
   30 continue
      fwg(1,5) = (1.0 - sfuel(ifg))*bbml
      fwg(1,6) = (bbm2*0.80)
      fwg(2,1)= sfuel(ifg)*bbml
      fwg(2,2)= (bbm2*0.20)

C ..... Writing current fuel values to external files
      if(irun .eq. 1) then
           write(8,1000) (fwg(1,l),l=1,4)
           write(9,1000) (fwg(1,l),l=5,6),(fwg(2,m),m=1,2)
      endif
C ##### FORMATS #####
 1000 format(7f10.3)
      return
      END
      SUBROUTINE grow(dbh,pd,ntrees,sla,grf,s1,s2,s3,age,kyr,itop,
     &                 inend,npine)
C ***************************************************************************
C This subroutines calculates the annual growth increment for each species. *
C Program logic is:                                                          *
C   1.  Compute basal area of stand and subsequent reduction factor.        *
C   2.  Compute reduction factor for climatic effects - DEGD.               *
C   3.  Compute leaf area and subsequent reduction factor for shading.      *
```

```
C   4.  Calculate growth increment and reduce by each computed factor.       *
C   5.  Compute tree mortality from random and stress factors.               *
C   6.  Remove tree if computed to be dead.                                  *
C Important variables include:                                               *
C   BAR - Basal area of stand in cm**2                                       *
C   DEGD - number of degree days for simulation stand.                       *
C   T - growth reduction factor for climatic effects.                        *
C   S - reduction factor for soil fertility effects.                         *
C   AL - proportion of available light to a given tree.                      *
C   H - tree height in cm                                                    *
C   DINC - diameter growth increment for current simulation year in cm       *
C   ISHADE(i) - shade tolerance category for species i.                      *
C   GRF(i) - growth reduction factor for pollution for species i.            *
C   GRWS(i) - growth reduction factor for water stress for species i.        *
C   AGEMX(i) - maximum attainable age for species i.                         *
C   PP(i) - probability of random mortality.                                 *
C   MORT,B1,B2,B3,CEXT - equation coefficients.                              *
C   AINC(i) - minimum possible diameter growth for species i.                *
C Subroutines called:                                                        *
C   SHADE - computes leaf area index by height class.                        *
C   ERROR - prints error messages if run bounds are violated.                *
C ****************************************************************************
      dimension dbh(1),ntrees(1),sla(1),pd(1),grf(1),s1(1),s2(1),
     &          s3(1),age(1),itop(1)
      character*1 ishade,imoist,spp*4,spec*4
      common/leaf/aside(7),c(7),alpha(7),b2(7),b3(7),cext(8),crat(7),
     &            sigma(7),ap(7),betap(7)
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      common/trunk/g(7),agemx(7),dm(7),hm(7),spm(8),ysc(7)
      common/water/grws(7),ws0(7),wsm(7),nws(7),wr,grdd(7),grbar(7)
      common/hdata/phi,xmbar(8),degd,ainc(7),binfest(8),ibcycle(8),brr
      common/climat/dmin(7),dopt(7),dmax(7),baset(12),basep(12),baseh
      common/types/ishade(7),imoist(7),spp(7)
      common/plotq/elev,rock,till,soilm,text,excess,pltsiz,ifg
      integer clrcut
      real mort(2)
      data pi/3.14159265/,mort/0.328,0.100/

      nlive = 0
      n= isum(ntrees,ns)
      if(n.eq.0)return
      if(kyr .lt. impb) then
           inend = 0
      elseif(kyr .eq. impb) then
           inend = kyr + ibcycle(ifg)
      endif

C ..... Compute total basal area of entire stand
      bar= 0.
      do 5 j= 1,n
        bar= bar+(pi/4.)*dbh(j)**2
    5 continue

C ..... Compute shading leaf area for each tree
      call shade(ntrees,dbh,sla,s1,s2,s3,pltsiz)
      do 10 i=1,ns

C ..... Calculate soil fertility reduction factor from basal area
         grbar(i) = 1.0 - bar / (xmbar(ifg) * 10000.0 * pltsiz)
```

```
          ni= ntrees(i)
          if (ni.eq.0) go to 10
          if(i .eq. 1) then
               jj = 0
          else
               jj= isum(ntrees,i-1)
          endif
          do 20 j= 1,ni

C ..... Compute standardized available light, then calculated growth
C ..... increment (maximum)
             al= phi*exp(-cext(ifg)*sla(j+jj))
             h= 137.+b2(i)*dbh(j+jj)-b3(i)*dbh(j+jj)**2.0
             dinc= g(i)*dbh(j+jj)*(1.-h*dbh(j+jj)/(hm(i)*dm(i)))
             dinc=dinc/(274.+3.*b2(i)*dbh(j+jj)-4.*b3(i)*dbh(j+jj)**2.0)

C ..... Reduce diameter increment for shading effects
             if(ishade(i).eq.'i' .or. ishade(i) .eq. 'I') then
                  dinc = 2.24*(1.-exp(-1.136*(al-.08)))*dinc
             elseif(ishade(i) .eq. 't' .or. ishade(i) .eq. 'T' .or.
     &              ishade(i) .eq. 'm' .or. ishade(i) .eq. 'M') then
                  dinc = (1.-exp(-4.64*(al-.05)))*dinc
             endif

C ..... Reduce diameter increment using environmental growth reduction factors

             dinc= dinc * grf(i) * grws(i) * grdd(i) * grbar(i)
             if (dinc .gt. 5.0) call error(11)

C ..... Calculate tree mortality for random and stress factors
             if(spp(i) .eq. 'pial') then
                  pd(j+jj) = 3.0 / agemx(i)
             else
                  pd(j+jj) = 4.0 / agemx(i)
             endif
             if (dinc .lt. ainc(i)) then
                  if(ishade(i) .eq. 'I' .or. ishade(i) .eq. 'i') then
                     pd(j+jj) = pd(j+jj) + mort(1) - (mort(1)*pd(j+jj))
                  else
                     pd(j+jj) = pd(j+jj) + mort(2) - (mort(2)*pd(j+jj))
                  endif
             endif

C ..... Calculate tree mortality if blister rust infection
             if(kyr .ge. ibr) then
                  if(spp(i) .eq. 'pial' .or. spp(i) .eq. 'pimo') then
                       dia = dbh(j+jj)
                       tage = age(j+jj)
                       infec = itop(j+jj)
                       if(infec .eq. 0) then
                            rnum = rnd()
                            if(rnum .lt. pinfec) itop(j+jj) = 1
                       endif
                       call rust(dia,tage,prob,pinfec,infec)
                       pd(j+jj) = pd(j+jj) + prob
                  endif
             endif

C ..... Calculate tree mortality if mountain pine beetle infestation
             if(kyr .eq. impb) then
```

```
                if(spp(i) .eq. 'pial' .or. spp(i) .eq. 'pico'
     &          .or. spp(i) .eq. 'pipo' .or. spp(i) .eq.
     &          'pimo') then
                     if(dbh(j+jj) .gt. 10.0) then
                          npine = npine + 1
                          nlive = nlive + 1
                     endif
                endif
           endif
           if(kyr .gt. impb .and. kyr .le. inend) then
                if(spp(i) .eq. 'pial' .or. spp(i) .eq. 'pico' .or.
     &             spp(i) .eq. 'pipo' .or. spp(i) .eq. 'pimo') then
                     dia = dbh(j+jj)
                     tage = age(j+jj)
                     spec = spp(i)
                     call beetle(spec,dia,tage,prob)
                     pd(j+jj) = pd(j+jj) + prob
                     if(dbh(j+jj) .gt. 10.0) then
                          nlive = nlive + 1
                     endif
                endif
           endif

C ..... Incrementing individual tree diameter
           dbh(j+jj) = dbh(j+jj) + dinc
   20    continue
   10 continue
      if(npine .gt. 0) then
           pinfest = 1.0 - float(nlive) / float(npine)
      else
           pinfest = 1.0
      endif
      if(kyr .gt. inend .or. pinfest .ge. binfest(ifg)) inend = 0
      return
      END
      SUBROUTINE injury(ntrees,dbh,byram,p,hs,icwf)
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C This subroutine calculates scorch height then estimates tree mort-   :
C  ality from scorch height using the function RISK.  Parameters for   :
C  RISK include percent crown scorched, DBH, and scorch height.        :
C Variables are:                                                       :
C     c1,c2,c3 ... coefficients for byrams equation                    :
C     byram ...... byrams fire intensity (kw/m)                        :
C     wind....... wind speed            (km/hr)                        :
C     tkill ...... lethal foliage temperature  (deg cent)              :
C     bc ......... ratio of bark thickness to diameter at breast height:
C     hs ......... crown scorch height in meters                       :
C     p .......... prob tree dies within one year                      :
C     t .......... ambient air temperature  (deg cent)                 :
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      common/leaf/aside(7),c(7),alpha(7),b2(7),b3(7),cext(8),crat(7),
     &            sigma(7),ap(7),betap(7)
      common/sites/ occur(500),rh,wind,ttheta,t
      common/mort/ d1(7),d2(7),d3(7),bc(7)
      integer clrcut
      dimension ntrees(1),dbh(1),p(1)
      data c1/.7422/,c2/.02559/,c3/.2778/,tkill/60./,hsmin/.1/

      n= isum(ntrees,ns)
```

```
      if (n.eq.0) return

C ..... Byrams equation for crown scorch height
      hs= c1*byram**1.1667/(sqrt(c2*byram+(c3*wind)**3)*(tkill-t))
      if (hs.lt.hsmin) return
      do 10 k= 1,ns
           kkk = k
           nk= ntrees(k)
           if (nk.eq.0) go to 10
           if(kkk .eq. 1) then
                jj = 0
           else
                jj= isum(ntrees,kkk-1)
           endif
           do 20 j= 1,nk

C ..... Calculation of crown scorch volume (Ryan Rheinhardt)
                ht = (137.+b2(k)*dbh(j+jj)-b3(k)*dbh(j+jj)**2)/100.0
                hcr = crat(k)*ht
                b = hs - (ht - hcr)
                if(b .le. 0.0) b = 0.0
                if(b .ge. hcr) b = hcr
                ck = 100.0 * (b*(2*hcr-b)/(hcr**2.0))
                dia = dbh(j+jj)

C ..... Estimation of probability of tree mortality from fire
                if(icwf .eq. 1) then
                     p(j+jj) = 1.00
                else
                     p(j+jj)= risk(ck,dia,kkk)
                endif
   20      continue
   10 continue
      return
      END
      SUBROUTINE kill(nalive,ndead,dbh,pd,u,age,branch,itop,icwf)
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C : Subroutine kill eliminates trees from simulation plot by first   :
C : generating a random number (u(k)) and comparing it with current  :
C : probability of death for a given tree (p(i)).  If u(k) less than :
C : p(i) the tree is removed and the standing woody fuel is distrib- :
C : uted on plot with subroutine SNAG.                               :
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      common/limits/ mxtrs,maxspc,mxdd,mxyrs,maxbin
      common/leaf/aside(7),c(7),alpha(7),b2(7),b3(7),cext(8),crat(7),
     &            sigma(7),ap(7),betap(7)
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      integer clrcut
      dimension nalive(1),ndead(1),dbh(1),pd(1),u(1),age(1),
     &          itop(1)

      n= isum(nalive,ns)
      if (n.eq.0) return

C ..... Call the random number generator and initialize
      call rgen(u,n)
      indx1= 0
      ksp= 0
      ksum= 0
```

```
C ..... Calculate mortality by tree and species
      do 10 k= 1,n
    5      if (k.le.ksum) go to 6
           ksp= ksp+1
           ksum= ksum+nalive(ksp)
           go to 5

C ..... If a tree lives:
    6      if (u(k).gt.pd(k)) then
                indx1= indx1+1
                dbh(indx1)= dbh(k)
                age(indx1)=age(k)+1.0
                pd(indx1)= pd(k)
                itop(indx1) = itop(k)
           else

C ..... If a tree dies:
                dia = dbh(k)
                if(icwf .eq. 0) call snag(dia,branch,ksp)
                nalive(ksp)= nalive(ksp)-1
                ndead(ksp)= ndead(ksp)+1
           endif
   10 continue
      return
      END
      SUBROUTINE loader(ntrees,dbh,lnl,ln,dnl,dn,wood,yr,branch,icwf)
C ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C  This subroutine adds woody fuel, duff and litter to the forest floor. :
C  Woody fuel is collected in WOOD(i) while litter is stored in LN(i).   :
C  The duff weight is also calculated and stored in DN(i).               :
C  The output variables:                                                 :
C     fyr .... number of years to reach maximum fuel loadings            :
C     fload .. maximum fuel loading for woody fuel in a fire group       :
C     lnl .... previous year's litter loading for 100 sq meters stand    :
C     ln  .... current year litter loading for 100 sq meters             :
C              fuel properties                                           :
C     dkl .... litter decay constants                                    :
C     ltd .... litter to duff conversion constants                       :
C     dkf .... fresh litter fall decay constants                         :
C     dkd .... duff decay constants                                      :
C              leaf properties                                           :
C     ffl .... fraction of leaf biomass which  falls in one year         :
C ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      dimension ntrees(1),dbh(1)
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      common/plotq/elev,rock,till,soilm,text,excess,pltsiz,ifg
      common/polut/ndyr(7),dmoist
      common/fuel3/ dkl(7),dkd(7),dkf(7),ltd(7)
      common/fuel4/ abm(7),ffl(7),fyr(3,8),fload(3,8)
      real ln(1),lnl(1),dn(1),dnl(1),wood(3)
      real dkl,dkd,dkf,ltd,abm,ffl,fnl(7),litduff
      integer clrcut,yr,fyr
      data litduff/0.100/

C ..... Initializing fuel loadings for start of simulation
      if(yr .eq. 1 .or. icwf .eq. 1) then
          do 5 i = 1,3

C ..... If the stand has been clearcut
                if(clrcut .eq. 1) then
```

```
                        wood(i) = fload(i,ifg)/float(fyr(i,ifg))
                        do 1 j = 1,ns
                             ln(j) = litduff * 0.25
                             dn(j) = litduff * 0.75
    1                   continue
                   elseif(icwf .eq. 1) then

C ..... if stand has had a crown fire
                        wood(i) = (fload(i,ifg)/float(fyr(i,ifg)))*0.1
                        do 2 j = 1,ns
                             ln(j) = litduff * 0.25
                             dn(j) = litduff * 0.75
    2                   continue
                   else

C ..... If the stand is mature
                        wood(i) = fload(i,ifg)/(float(fyr(i,ifg))/2.0)
                        do 3 j = 1,ns
                             ln(j) = litduff * 0.25
                             dn(j) = litduff * 0.75
    3                   continue
                   endif
    5         continue
              branch = 0.0
              return
         endif

C ..... Calculating needlefall then litter accumulation
         do 10 k= 1,ns
           kkk = k
           dnl(k)= dn(k)
           lnl(k)= ln(k)
           nk= ntrees(k)
           if (nk.eq.0) go to 10
           if(kkk .eq. 1) then
                jj = 0
           else
                jj= isum(ntrees,kkk-1)
           endif
           call needle(sla,jj,nk,dbh,kkk,wgt,pltsiz)
           if(clrcut .eq. yr) then
                fnl(k)= wgt/(1000.0*pltsiz)
           else
                fnl(k)= wgt/(1000.0*float(ndyr(k))*pltsiz)
           endif

C ..... The dynamic loading equations for litter and duff components
           ln(k)= lnl(k)*(1.-dkl(k)-ltd(k))+fnl(k)*(1.-dkf(k))
           dn(k)= dnl(k)*(1.-dkd(k))+lnl(k)*ltd(k)
   10 continue

C ..... Calculation of woody fuel components - 1,10,100 hour fuels
         do 30 i = 1,3
              if(wood(i) .lt. fload(i,ifg)) then
                   wood(i) = wood(i) + fload(i,ifg)/float(fyr(i,ifg))
     &                        + ((branch * 0.333) / pltsiz)
              else
                   wood(i) = fload(i,ifg)
              endif
   30 continue
```

```
      branch = 0.0
      return
      END
      SUBROUTINE needle(sla,ikk,nkk,dbh,kk,wgt,pltsiz)
C *********************************************************************
C This subroutine calculates the crown weight from equations in   Brown *
C (1984) then gets the percentage of the weight that is foiliage from   *
C subroutine PFOIL.  Using these and other species-specific parameters  *
C the leaf area index SLA of the stand is estimated.                    *
C *********************************************************************
      character*1 imoist,ishade,spp*4
      common/leaf/aside(7),c(7),alpha(7),b2(7),b3(7),cext(8),crat(7),
     &            sigma(7),ap(7),betap(7)
      common/types/ishade(7),imoist(7),spp(7)
      dimension dbh(1)

      sla = 0.0
      wgt = 0.0

C ..... Calculate the weight of live crown by species
      do 10 ii = 1,nkk
           dia = dbh(ii+ikk) * 0.3937
           call foil(pfoil,dia,kk)
           if(spp(kk) .eq. 'abla') then
                wt = (alpha(kk) + c(kk)*dia**(2.0))*453.59
           else
                wt = 453.59 * exp(alpha(kk) + c(kk)*alog(dia))
           endif
           wgt = wgt + wt * pfoil

C ..... Calculate the leaf area for this species
           sla = sla + ((wt / 0.5)*sigma(kk)/aside(kk))/(100000.0*
     &                 pltsiz)
   10 continue
      return
      END
      SUBROUTINE output(x,nyears)
C *****************************************************************
C This subroutine writes the average basal area of each tree for  *
C each year of simulation.  X(i,j) contains species' basal area.  *
C *****************************************************************
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      integer clrcut
      dimension x(nyears,1)

      open(unit=7,file='BASAL.DAT',pad='yes',recl=100)

C ..... Print the average basal area over nspan years to unit 7
      do 10 j= 1,nspan
           write(7,2000) (x(j,k),k=1,ns)
   10 continue
      close(7)
      return
 1000 format(i3,1x,i3)
 2000 format(7f10.3)
      END
      SUBROUTINE pinalb(fnj,sla,dbh,age,ntrees,itop,ccrop,cones)
C ********************************************************************
C *                    - subroutine pinalb -
C * This subroutine calculates the number of whitebark pine seedlings *
```

```
C * to establish on the simulation plot.  The algorithm is based on   *
C * a cone:bird ratio which indicates availability  of cones to the   *
C * Clark's nutcracker.  Excess cones are then available for bears    *
C * and squirrels.  In addition, the number of seedlings (or caches)  *
C * depends on density of foilage modeled as a function of leaf area  *
C * index.                                                            *
C *********************************************************************
      dimension dbh(1),age(1),itop(1)
      common/leaf/aside(7),c(7),alpha(7),b2(7),b3(7),cext(8),crat(7),
     &            sigma(7),ap(7),betap(7)
      common/hdata/phi,xmbar(8),degd,ainc(7),binfest(8),ibcycle(8),brr
      common/wbark/ cmax,agecon,dbhmin,birds,spc,spcac,cyr(4),fmax,cpt,
     &              pfind,ssc
      common/plotq/elev,rock,till,soilm,text,excess,pltsiz,ifg
      common/types/ishade(7),imoist(7),spp(7)
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      integer ntrees(1),clrcut
      character*1 ishade,imoist,spp*4
      data pw1,pw2,pw3,a1,a2,a3/5.0,5.0,5.5,0.6,0.6,0.8/
      data amin,aopt,amax/40.0,250.0,850.0/

C ..... Line functions for cacheability etc..
      pref(y) = 1.00 - ((exp(-(((y / fmax) - 1.0) / (a1 - 1.0))**pw1)
     &          - exp(-(-1.0 / (a1 - 1.0))**pw1)) /
     &          (1.0 - exp(-(-1.0 / (a1 - 1.0))**pw1)))
      frac(y) = 1.0 - ((exp(-(((y / cmax) - 1.0) / (a2 - 1.0))**pw2)
     &          - exp(-(-1.0 / (a2 - 1.0))**pw2)) /
     &          (1.0 - exp(-(-1.0 / (a2 - 1.0))**pw2)))
      cac(y) = exp((y / cmax)**(pw3) - (1.0 + 0.5 * ((cmax-y)/cmax)))

C ..... Initialize appropriate variables
      v = (amax - aopt) / (aopt - amin)
      cones = 0.0

C ..... Search to find if whitebark species is present
      do 20 i = 1,ns
           if(spp(i) .eq. 'pial') then
                ntrs = ntrees(i)

C ..... Calculation of cone bearing trees on plot
                ictree = 0
                if(i .eq. 1) then
                     ii = 0
                else
                     ii = isum(ntrees,i-1)
                endif
                do 1 j = 1,ntrs
                     if(dbh(j+ii) .gt. dbhmin .and. age(j+ii) .gt.
     &                  amin .and. age(j+ii) .le. amax) then
                          ictree = ictree + 1
                     endif
    1           continue

C ..... Calculation of relative size of cone crop
                rnum = rnd()
                do 5 j = 1,4
                     if(rnum .le. cyr(j)) then
                          confac = float(j-1) / 3.0
                          go to 6
                     endif
```

```
    5           continue

    6           if(ictree .le. 1) then
                     cones = ccrop * confac
                     go to 30
                endif

C ..... Calculation of number of cones per tree and then the summation
                if(i .eq. 1) then
                     ii = 0
                else
                     ii = isum(ntrees,i-1)
                endif
                do 10 j = 1,ntrs
                     if(dbh(j+ii) .gt. dbhmin .and. age(j+ii) .gt.
     &                  amin .and. age(j+ii) .le. amax) then
                           t = ((age(j+ii) - amin) *
     &                          (amax-age(j+ii))**v) /
     &                          (((amax-aopt)**v) *
     &                          (aopt - amin))
                           cones = (cpt * t) + cones
                           if(itop(j+ii) .eq. 1) cones = cones * 0.1
                     endif
   10           continue
                ccrop = cones
                if(cones .gt. 0.0) then
                     cones = cones * confac
                else
                     cones = cmax * 0.1 * confac
                endif
                go to 30
           endif
   20 continue
      return

C ..... Calculation of the number of caches on the plot
   30 caches = ((cones * spc) / spcac) * (1.0 - (pfind + ssc))
      if(caches .le. 0.0) caches = 0.0

C ..... Calculation of the cones per bird ratio
      cpb = ((cones / birds) / pltsiz) * 4046.849
      if(cpb .gt. cmax) cpb = cmax

C ..... Calculation of the fraction of cones available to griz
      fcone = frac(cpb)
      if(fcone .le. 0.2) fcone = 0.2
      if(fcone .gt. 0.9) fcone = 0.9

C ..... Calculation of the reduction factor for cacheability
      cabil = cac(cpb)

C ..... Calculation of the reduction factor for preferability (LAI)
      if(sla .gt. fmax) sla = fmax
      pleaf = pref(sla)
      if(pleaf .le. 0.1) pleaf = 0.1
      if(pleaf .gt. 1.0) pleaf = 1.0

C ..... Final calculation of seedlings started in current year FNJ
      fnj = caches * cabil * pleaf
```

```
      return
      END
      SUBROUTINE pollut(grf,kyr)
C ***************************************************************************
C This subroutine calculated growth reduction effects from air pollutants *
C  However, since air pollution effects are minimal in the Inland North-  *
C  west, the growth reduction factor for pollution was set equal to 1.0.  *
C Important Variables:                                                    *
C     grf(i).... growth reduction factor for species i                    *
C     cr(i)..... threshold of pollution damage for species i              *
C     sen(i).... sensitivity coefficient for species i                    *
C     ndyr(i)... number of years needles are retained for species i       *
C     cbar...... seasonal average so2 concentration ppm                   *
C     kyr....... current year                                             *
C     ns.......  number of tree species                                   *
C ***************************************************************************
      common/polut/ndyr(7),dmoist
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      integer clrcut
      dimension grf(1)
      if (ns.le.0) return
      if (kyr.eq.0) return

C ..... Set pollution growth reduction factor to 1.0 for Montana
      do 10 i= 1,ns
           grf(i)= 1.000
   10 continue
      return
      END
      SUBROUTINE rgen(x,i)
C **************************************************************************
C  Subroutines RGEN and RANST and function RAN are random number         *
C  generators for the model. Users should use their own random number    *
C  generators which return n random numbers u between 0 and 1 with       *
C  uniform distribution.  XRANDOM is a Perkin-Elmer generator.           *
C **************************************************************************
      dimension x(i)

C ..... Fill array x(i) with random numbers from XRANDOM
      do 10 j=1,i
           xx = rnd()
           x(j) = xx
   10 continue
      return
      END
      SUBROUTINE rings(n,u)
C ***************************************************************************
C Subroutine RINGS produces an array containing the simulation years that *
C are fire years.  This is a stochastic function where a random number is *
C generated (U(i)) and if less than p (set in the data statement) then    *
C a fire is to be simulated for that year.  The calculation is abandoned  *
C if IFYR is greater than zero (user specified fire years).               *
C Variables are:                                                          *
C    X(k) - fire year array containing 0 (no fire) or 1 (fire)            *
C    U(i) - random number array                                           *
C    R - number of years to block fires after a fire has been generated   *
C    PNB - probability of fire in a blocked year.                         *
C    IFYR - user specified fire interval                                  *
C ***************************************************************************
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
```

```
      common/sites/ x(500),rh,wind,ttheta,t
      integer x,r,yes,no,clrcut
      real u(1),ul(1)
      data r/3/,p/.0125/,yes/1/,no/0/
      if (n.eq.0) return

C ..... Initializing fire array
      do 10 i= 1,n
           x(i)= no
   10 continue

C ..... Assign fire years if user specified
      if(ifire .gt. 0) then
           ifyr = ifire
           do 20 k = 1,n
                if(k .eq. ifyr) then
                     x(k) = yes
                     ifyr = ifyr + ifire
                endif
   20      continue

C ..... Assign only one fire year if number is negative
      elseif(ifire .lt. 0) then
           ifyr = iabs(ifire)
           x(ifyr) = yes
           return

C ..... Calculate fire years using stochastic function
      else
           i= 0
           if (r.eq.1) go to 35

C ..... Calculate pnb, prob of an ublocked state
           pnb= 1./(p*float(r-1))
           call rgen(ul,1)
           if (ul(1).le.pnb) go to 35

C ..... Select an integer b at random from 1,2,3,... r-1
           call rgen(ul,1)
           i= int(float(r-1)*ul(1))+1
   35      call rgen(u,n)
   40      i= i+1
           if (i.gt.n) return
           if (u(i).gt.p) go to 40

C ..... Assign fire years
           x(i)= yes
           i= i+r-1
           go to 40
      endif

      return
      END
      SUBROUTINE rust(dia,age,prob,pinfec,infec)
C *********************************************************************
C This subroutine simulates individual tree mortality in the event    *
C of a blister rust infection.  Mortality functions are from          *
C                                                                     *
C *********************************************************************
```

```
      prob = 0.0
      if(infec .eq. 0) then
           pinfec = 0.50
      elseif(infec .eq. 1) then

C ..... Calculate prob mortality for 5 needle pine from equation
           prob = exp(-0.10*dia)
           if(age .gt. 850.0) prob = 0.99
      endif

      return
      END
      SUBROUTINE shade(ntrees,dbh,sla,h,temp,indx,pltsiz)
C ***************************************************************************
C This subroutine calculates the effective leaf area index by tree        *
C height to estimate shading effects for individual trees.  Logic is:    *
C   1.  Calculated leaf areas for every tree.                             *
C   2.  Sort leaf areas according to height.                              *
C   3.  Sum leaf areas by height.                                         *
C   4.  Reorder the cumulative leaf areas by DBH.                         *
C Variables are:                                                          *
C   TEMP(i) - temporary array containing leaf areas                       *
C   SLA(i) - working array for leaf areas                                 *
C   DBH(i) - array containing dbh for each tree on plot                   *
C   ALPHA,SIGMA,ASIDE,PLTSIZ - conversion factors for crown weight to     *
C                              leaf area                                  *
C Subroutines called:                                                     *
C   SORTP - sorts leaf area according to height                           *
C ***************************************************************************
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      integer clrcut
      character*1 imoist,ishade,spp*4
      common/types/ishade(7),imoist(7),spp(7)
      common/leaf/aside(7),c(7),alpha(7),b2(7),b3(7),cext(8),crat(7),
     &            sigma(7),ap(7),betap(7)
      common/trunk/g(7),agemx(7),dm(7),hm(7),spm(8),ysc(7)
      common/hdata/phi,xmbar(8),degd,ainc(7),binfest(8),ibcycle(8),brr
      dimension ntrees(1),dbh(1),sla(1),indx(1),temp(1),h(1)

C ..... Calculation of leaf area for each tree
      n= isum(ntrees,ns)
      if (n.eq.0) return
      do 10 k= 1,ns
           nk= ntrees(k)
           if (nk.eq.0) go to 10
           if(k .eq. 1) then
                kk = 0
           else
                kk= isum(ntrees,k-1)
           endif
           do 20 i= 1,nk
                h(i+kk)= 137.+b2(k)*dbh(i+kk)-b3(k)*dbh(i+kk)**2.0
                if(spp(k) .ne. 'abla') then
                     temp(i+kk) = ((exp(alpha(k)+c(k)*alog(dbh(i+kk)
     &                            /2.54))*453.59)/0.5)*
     &                            sigma(k)/aside(k)
                else
                     temp(i+kk) = (((alpha(k) + c(k)*(dbh(i+kk)/2.54)
     &                            **(2.0))*453.59)/0.5)*
     &                            sigma(k)/aside(k)
```

```
              endif
              temp(i+kk) = temp(i+kk)/(100000.0*pltsiz)
              indx(i+kk)= i+kk
   20      continue
   10 continue

C ..... Sort sla according to h
      call sortp(h,n,indx)
      do 40 j= 1,n
           k= indx(j)
           sla(j)= temp(k)
   40 continue

C ..... Compute final values of sla
      nml= n-1
      do 50 j= 1,nml
           temp(j)= sum(sla(j+1),n-j)
   50 continue
      temp(n)= 0.

C ..... Reorder elements of sla to correspond to dbh
      do 60 j= 1,n
           k= indx(j)
           sla(k)= temp(j)
   60 continue
      return
      END
      SUBROUTINE sitdta
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C This program reads in site specific data from an external file on  :
C device 3.  Values are then passed back to main driver.             :
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      common/plotq/elev,rock,till,soilm,text,excess,pltsiz,ifg
      common/climat/dmin(7),dopt(7),dmax(7),baset(12),basep(12),baseh
      common/hdata/phi,xmbar(8),degd,ainc(7),binfest(8),ibcycle(8),brr
      common/sites/ occur(500),rh,wind,ttheta,t
      common/polut/ndyr(7),dmoist
      common/fuel5/ amc(7),bmc(7),cmc(7),dmc(7),mmc(7),tmc,emc(7)
      character*10 name

      open(unit=3,file='SITE.DAT',form='formatted',
     &     recl=150,pad='yes')

C ..... Read in site specific data for simulation plot
      read (3,1000) name, (baset(j),j=1,12)
      write(5,1000) name, (baset(j),j=1,12)
      read (3,1000) name, (basep(j),j=1,12)
      write(5,1000) name, (basep(j),j=1,12)
      read (3,2000) name, baseh
      write(5,2000) name, baseh
      read (3,2000) name, excess
      write(5,2000) name, excess
      read (3,2000) name, phi
      write(5,2000) name, phi
      read (3,2000) name, text
      write(5,2000) name, text
      read (3,2000) name, rock
      write(5,2000) name, rock
      read (3,2000) name, elev
      write(5,2000) name, elev
```

```
      read (3,3000) name, ifg
      write(5,3000) name, ifg
      read (3,2000) name, till
      write(5,2000) name, till
      read (3,2000) name, rh
      write(5,2000) name, rh
      read (3,2000) name, wind
      write(5,2000) name, wind
      read (3,2000) name, ttheta
      write(5,2000) name, ttheta
      read (3,2000) name, t
      write(5,2000) name, t
      read (3,2000) name,pltsiz
      write(5,2000) name,pltsiz
      read (3,4000) name,(emc(j),j=1,7)
      write(5,4000) name,(emc(j),j=1,7)
      read (3,2000) name,dmoist
      write(5,2000) name,dmoist
      read (3,2000) name,brr
      write(5,2000) name,brr
      rewind 3
      close(3)
      return
 1000 format(a10,12f5.2)
 2000 format(a10,f10.3)
 3000 format(a10,i10)
 4000 format(a10,7f10.3)
      END
      SUBROUTINE site
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C This subroutine calculates all site parameters that are used in the :
C various algorithms throughout the program.  Actual and potential    :
C evapotranspiration are calculated along with water stress growth    :
C reduction factors.  New calculations are passed to main program.    :
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      dimension sitet(12),pp(12)
      dimension pei(12),actei(12),stori(12)
      common/water/grws(7),ws0(7),wsm(7),nws(7),wr,grdd(7),grbar(7)
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      common/plotq/elev,rock,till,soilm,text,excess,pltsiz,ifg
      common/climat/ dmin(7),dopt(7),dmax(7),baset(12),basep(12),baseh
      common/hdata/phi,xmbar(8),degd,ainc(7),binfest(8),ibcycle(8),brr
      character*6 nsoilq,nheati,nsoilm,nape*4,nspe*4,nwra*4
      character*5 ndiff,ndegd,ngrws,na*2,npe*3,nacte,nstor
      character nwr*3,nsat*4,nwrs*4
      integer clrcut
      data nsoilq/' soilq'/,ndiff/' diff'/,ndegd/' degd'/
      data nheati/' heati'/,na/' a'/,npe/' pe'/,nacte/' acte'/
      data nsoilm/' soilm'/,nstor/' stor'/
      data nwr/' wr'/,ngrws/' grws'/,nsat/' sat'/
      data nwra/' wra'/,nape/' ape'/,nwrs/' wrs'/,nspe/' spe'/

      rocky= (100.-  rock)/100.

C ..... Rock is percent of surface area in rock outcrop
C ..... Till is depth of watering or root zone in feet.
C ..... Text is amount of available water for storage in mm/m

      till=till/3.2808
      xmbar(ifg) = xmbar(ifg)*rocky
```

```
      diff=baseh-elev
      tmin=baset(1)+(2.2*diff/1000.)
      tmax=baset(7)+(3.6*diff/1000.)
      tave=(tmax+tmin)/2.
      t=40.
      if(tmin.gt.t) write(5,98)

   98 format(1h ,' --------- you cant use minimum january temperature',
     1's greater than 40',1h ,'without modifying SUBROUTINE ',
     2'site -----------')

      if(tmax.lt.tmin) write(5,99)

   99 format(1h ,'---------- to work in the southern hemisphere one ',
     1'must modify SUBROUTINE site --------')

      degd=(365./(2.*3.14159))*(tmax-tmin)-(365./2.)*(t-tave) + (
     1(365./3.14159)*(t-tave)**2 )/(tmax-tmin)

C ..... Calculation of actual and potential evapotranspiration.
      heati=0.
      soilm=0.
      do 10 i=1,12
           sitet(i)=baset(i) + 3.6*diff/1000.
           sitet(i)=(5./9.)*(sitet(i)-32.)
           pp(i)=basep(i)*25.4
           if(sitet(i).le.0.0) go to 10
C ..... Calculation of intermediate heat index
           heati=heati+(sitet(i)/5.0)**1.514
   10 continue

C ..... Calculation of intermediate exponent in thornwaithes equation
      a=(9.675*(heati**3.)-77.1*heati**2+17920.*heati+492390.)*.000001
      m=1

C ..... Computation of storage capacity of soil
      strmax=amin1(till,10.)*text*rocky

C ..... Calculation of the water balance equation
      do 250 i=1,12
           if(sitet(i).le.0.0) go to 250
           pe=16.*(((10.*sitet(i))/heati)**a)
           if(m.gt.1) go to 220
           stor=strmax
           m=2
  220      if(pe.ge.stor + excess*pp(i)) go to 230
           acte=pe
           go to 240
  230      acte=stor+excess*(amin1(pp(i),strmax))
  240      stor=amin1(strmax,stor-acte+pp(i))
           soilm=soilm + acte
           pei(i)=pe
           actei(i)=acte
           stori(i)=stor
  250 continue
      ape=0.0
      do 300 i=1,12
           ape=ape+pei(i)
  300 continue
```

```
C ..... Calculation of the water stress reduction factor parameters
C ..... Ape=annual potential evapotranspiration
C ..... Soilm= annual actual evapotranspiration
C ..... Spe=seasonal potential evapotranspiration
C ..... Sat= seasonal actual evapotranspiration
C ..... Wra=annual actual et/annual potentail et
C ..... Wrs=seasonal actaul et/seasonal potentail et
      spe=0.0
      sat=0.0
      do 301 i=4,10
           spe=spe+pei(i)
  301      sat=sat+actei(i)
      wra=soilm/ape
      wrs=sat/spe
      wr=wra
C ..... Call wrstrs to figure reduction factor then write results to file
      call wrstrs
      write(5,3000)
      write(5,1000) nsoilq,xmbar(ifg)
      write(5,1000) ndiff,diff
      write(5,1000) ndegd,degd
      write(5,1000) nheati,heati
      write(5,1000) na,a
      write(5,1000) nsoilm,soilm
      write(5,2000) npe,(pei(k),k=1,12)
      write(5,2000) nacte,(actei(k),k=1,12)
      write(5,2000) nstor,(stori(k),k=1,12)
      write(5,1000) nwr,wr
      write(5,4000) ngrws,(grws(k),k=1,ns)
      write(5,4000) ndegd,(grdd(k),k=1,ns)
      write(5,1000) nwra,wra
      write(5,1000) nape,ape
      write(5,1000) nwrs,wrs
      write(5,1000) nspe,spe
      write(5,1000) nsat,sat
 1000 format(1x,a8,f10.3)
 2000 format(a8,12f5.1)
 3000 format(10x,'calculated parameters in site')
 4000 format(a8,7f10.4)
      return
      END
      SUBROUTINE snag(dbh,branch,kk)
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C  This subroutine adds the branchwood material of a dead tree to  :
C  the woody fuel components.  BRANCH variable holds the total     :
C  biomass of the dead woody branchwood until subroutine FIRE then :
C  equal values of BRANCH go into the three woody fuel types WOOD. :
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      character*1 imoist,ishade,spp*4
      common/types/ishade(7),imoist(7),spp(7)
      common/leaf/aside(7),c(7),alpha(7),b2(7),b3(7),cext(8),crat(7),
     &            sigma(7),ap(7),betap(7)

C ..... Calculate the downed woody fuel from a dead snage
      dbh = dbh*0.3937
      if(spp(kk) .eq. 'abla') then
           wt = (alpha(kk) + c(kk)*(dbh)**(2.0))*0.045359
      else
           wt = exp(alpha(kk)+c(kk)*alog(dbh))*0.045359
      endif
```

```
C ..... Calculate the weight of needlefall
      call foil(pfoil,dbh,kk)
      branch = branch + wt*(1.0 - pfoil)

      return
      END
      SUBROUTINE sortp(a,n,b)
C ***************************************************************************
C This subroutine sorts leaf area by height of individual trees, then    *
C passes the manipulated array back to subroutine GROW.                  *
C ***************************************************************************
      dimension a(n)
      integer b(n)
      dimension iu(16),il(16)
      integer p

      i=1
      j=n
      m=1
    5 if(i.ge.j) go to 70

C first order a(i),a(j),a((i+j)/2), and use median to split the data
   10 k=i
      ij=(i+j)/2
      t=a(ij)
      it=b(ij)
      if(a(i).le.t) go to 20
      a(ij)=a(i)
      b(ij)=b(i)
      a(i)=t
      b(i)=it
      t=a(ij)
      it=b(ij)
   20 l=j
      if(a(j).ge.t) go to 40
      a(ij)=a(j)
      b(ij)=b(j)
      a(j)=t
      b(j)=it
      t=a(ij)
      it=b(ij)
      if(a(i).le.t) go to 40
      a(ij)=a(i)
      b(ij)=b(i)
      a(i)=t
      b(i)=it
      t=a(ij)
      it=b(ij)
      go to 40
   30 a(l)=a(k)
      b(l)=b(k)
      a(k)=tt
      b(k)=itt
   40 l=l-1
      if(a(l).gt.t) go to 40
      tt=a(l)
      itt=b(l)
C split the data into a(i to l).lt.t, a(k to j).gt.t
   50 k=k+1
```

```
      if(a(k).lt.t) go to 50
      if(k.le.1) go to 30
      p=m
      m=m+1
C split the larger of the segments
      if(l-i.le.j-k) go to 60
      il(p)=i
      iu(p)=l
      i=k
      go to 80
   60 il(p)=k
      iu(p)=j
      j=l
      go to 80
   70 m=m-1
      if(m.eq.0) return
      i=il(m)
      j=iu(m)
C short sections are sorted by bubble sort
   80 if(j-i.gt.10) go to 10
      if(i.eq.1) go to 5
      i=i-1
   90 i=i+1
      if(i.eq.j) go to 70
      t=a(i+1)
      it=b(i+1)
      if(a(i).le.t) go to 90
      k=i
  100 a(k+1)=a(k)
      b(k+1)=b(k)
      k=k-1
      if(t.lt.a(k)) go to 100
      a(k+1)=t
      b(k+1)=it
      go to 90
      END
      SUBROUTINE starter(ntrees,dbh,age)
C **********************************************************************
C This subroutine exchanges dbh and age information from temporary     *
C arrays to the working arrays.  This initially places the trees in    *
C the simulation plot.                                                 *
C **********************************************************************
      common/init/ ntrees0(7),dbh0(4000),ncount(20,7),nbins,width
     1  ,age0(4000),agein(20,7)
      common/limits/ mxtrs,maxspc,mxdd,mxyrs,maxbin
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      integer clrcut,agein
      dimension ntrees(1),dbh(1),age(1)

      do 10 j= 1,ns
        ntrees(j)= ntrees0(j)
   10 continue

      do 20 j= 1,mxtrs
        dbh(j)= dbh0(j)
        age(j)=age0(j)
   20 continue
      return
      END
      SUBROUTINE tree(nl,crop,cblock)
```

```
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C  This subroutine reads in species and fuel specific data for model sim- :
C  lation area (NRM).  Each input value is stored in appropriate COMMON   :
C  block or brought back to main driver.  Each value is also printed in   :
C  a file on device 5 for proof of correct entry.  Values are stratified  :
C  by species (dimensioned to seven) or fire group (dimensioned to eight).:
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      common/plotq/elev,rock,till,soilm,text,excess,pltsiz,ifg
      common/limits/ mxtrs,maxspc,mxdd,mxyrs,maxbin
      common/water/grws(7),ws0(7),wsm(7),nws(7),wr,grdd(7),grbar(7)
      common/leaf/aside(7),c(7),alpha(7),b2(7),b3(7),cext(8),crat(7),
     &            sigma(7),ap(7),betap(7)
      common/trunk/g(7),agemx(7),dm(7),hm(7),spm(8),ysc(7)
      common/hdata/phi,xmbar(8),degd,ainc(7),binfest(8),ibcycle(8),brr
      common/climat/ dmin(7),dopt(7),dmax(7),baset(12),basep(12),baseh
      common/birthk/sura(7),surb(7),dbulk(8,2),disequ(2,7),rdelay(8)
      common/wbark/ cmax,agecon,dbhmin,birds,spc,spcac,cyr(4),fmax,cpt,
     &              pfind,ssc
      common/types/ishade(7),imoist(7),spp(7)
      common/fuel1/ mext(2),rhop(2,7),bulk(2,8),mois(2,7)
      common/fuel2/ mps(2,7),lhv(2,7),st(2,7),se(2,7)
      common/fuel3/ dkl(7),dkd(7),dkf(7),ltd(7)
      common/fuel4/ abm(7),ffl(7),fyr(3,8),fload(3,8)
      common/fuel5/ amc(7),bmc(7),cmc(7),dmc(7),mmc(7),tmc,emc(7)
      common/mort/ d1(7),d2(7),d3(7),bc(7)
      common/polut/ndyr(7),dmoist
      common/cfire/cbd(7),vfl(7),cfmc(7),vfmc(7),cflm(7),csvr(7),
     &             vsvr(7),bl(7)
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      integer clrcut,count,cblock(7),fyr
      real mext,lhv,mmc,mps,ltd,mois,crop(7),cyr
      character*10 mark,chr,name,spp*4
      character*1 imoist,ishade
      data mark/'$$$$$$$$$$'/

      open(unit=2,file='TREE1.DAT',form='formatted',
     &     recl=150,pad='YES')

      n1= 2
C ..... Find number of species
      count= 0
   10 count= count+1
      read(2,1000,end=100) chr

      if (chr.ne.mark) go to 10
      rewind 2
      ns= count-1
      if (ns.gt.maxspc) call error(7)
C ..... Write header information
      do 20 i= 1,ns
           read(2,2000) spp(i)
           write(5,2000) spp(i)
   20 continue
      write(5,1000) mark
      read (2,1000) mark
      read (2,3000) name, (hm(j),j=1,ns)
      write(5,3000) name, (hm(j),j=1,ns)
      read (2,3000) name, (dm(j),j=1,ns)
      write(5,3000) name, (dm(j),j=1,ns)
      read (2,3000) name, (agemx(j),j=1,ns)
```

```
      write(5,3000) name, (agemx(j),j=1,ns)
      read (2,3000) name, (dmin(j),j=1,ns)
      write(5,3000) name, (dmin(j),j=1,ns)
      read (2,3000) name, (dopt(j),j=1,ns)
      write(5,3000) name, (dopt(j),j=1,ns)
      read (2,3000) name, (dmax(j),j=1,ns)
      write(5,3000) name, (dmax(j),j=1,ns)
      read (2,8000) name, (spm(j),j=1,8)
      write(5,8000) name, (spm(j),j=1,8)
      read (2,6000) name, (aside(j),j=1,ns)
      write(5,6000) name, (aside(j),j=1,ns)
      read (2,3000) name, (c(j),j=1,ns)
      write(5,3000) name, (c(j),j=1,ns)
      read (2,6000) name, (alpha(j),j=1,ns)
      write(5,6000) name, (alpha(j),j=1,ns)
      read (2,3000)  name, (sigma(j),j=1,ns)
      write(5,3000) name, (sigma(j),j=1,ns)
      read (2,6000) name, (ap(j),j=1,ns)
      write(5,6000) name, (ap(j),j=1,ns)
      read (2,6000) name, (betap(j),j=1,ns)
      write(5,6000) name, (betap(j),j=1,ns)
      read (2,8000) name, (cext(j),j=1,8)
      write(5,8000) name, (cext(j),j=1,8)
      read (2,5000) name, (ishade(j),j=1,ns)
      write(5,5000) name, (ishade(j),j=1,ns)
      read (2,5000) name, (imoist(j),j=1,ns)
      write(5,5000) name, (imoist(j),j=1,ns)
      read (2,8000) name, (xmbar(j),j=1,8)
      write(5,8000) name, (xmbar(j),j=1,8)
      read (2,6000) name, (crat(j),j=1,ns)
      write(5,6000) name, (crat(j),j=1,ns)
      read(2,3000)  name, mext(1)
      write(5,3000) name, mext(1)
      read(2,3000)  name, (amc(k),k=1,ns)
      write(5,3000) name, (amc(k),k=1,ns)
      read(2,3000)  name, (bmc(k),k=1,ns)
      write(5,3000) name, (bmc(k),k=1,ns)
      read(2,3000)  name, (cmc(k),k=1,ns)
      write(5,3000) name, (cmc(k),k=1,ns)
      read(2,3000)  name, (dmc(k),k=1,ns)
      write(5,3000) name, (dmc(k),k=1,ns)
      read(2,3000)  name, (mmc(k),k=1,ns)
      write(5,3000) name, (mmc(k),k=1,ns)
      read(2,3000)  name, tmc
      write(5,3000) name, tmc
      read(2,3000)  name, (rhop(1,k),k=1,6)
      write(5,3000) name, (rhop(1,k),k=1,6)
      read(2,8000)  name, (bulk(1,k),k=1,8)
      write(5,8000) name, (bulk(1,k),k=1,8)
      read(2,3000)  name, (lhv(1,k),k=1,6)
      write(5,3000) name, (lhv(1,k),k=1,6)
      do 50 i = 1,ifg
           read(2,3000)  name, (mps(1,k),k=1,6)
           if(i .eq. ifg) write(5,3000) name, (mps(1,k),k=1,6)
   50 continue
      do 60 i = 1,8-ifg
           read(2,1000) mark
   60 continue
      read(2,3000)  name, (st(1,k),k=1,6)
      write(5,3000) name, (st(1,k),k=1,6)
```

```
read(2,3000)  name, (se(1,k),k=1,6)
write(5,3000) name, (se(1,k),k=1,6)
read(2,4000)  name, (dkl(k),k=1,ns)
write(5,4000) name, (dkl(k),k=1,ns)
read(2,4000)  name, (ltd(k),k=1,ns)
write(5,4000) name, (ltd(k),k=1,ns)
read(2,4000)  name, (dkf(k),k=1,ns)
write(5,4000) name, (dkf(k),k=1,ns)
read(2,4000)  name, (dkd(k),k=1,ns)
write(5,4000) name, (dkd(k),k=1,ns)
read(2,4000)  name, (ffl(k),k=1,ns)
write(5,4000) name, (ffl(k),k=1,ns)
read(2,4000)  name, (dl(k),k=1,ns)
write(5,4000) name, (dl(k),k=1,ns)
read(2,3000)  name, (d2(k),k=1,ns)
write(5,3000) name, (d2(k),k=1,ns)
read(2,3000)  name, (d3(k),k=1,ns)
write(5,3000) name, (d3(k),k=1,ns)
read(2,3000)  name, (bc(k),k=1,ns)
write(5,3000) name, (bc(k),k=1,ns)
read(2,3000)  name, (rhop(2,k),k=1,nl)
write(5,3000) name, (rhop(2,k),k=1,nl)
read(2,3000)  name, (bulk(2,k),k=1,nl)
write(5,3000) name, (bulk(2,k),k=1,nl)
read(2,3000)  name, (lhv(2,k),k=1,nl)
write(5,3000) name, (lhv(2,k),k=1,nl)
read(2,3000)  name, (mps(2,k),k=1,nl)
write(5,3000) name, (mps(2,k),k=1,nl)
read(2,3000)  name, (st(2,k),k=1,nl)
write(5,3000) name, (st(2,k),k=1,nl)
read(2,3000)  name, (se(2,k),k=1,nl)
write(5,3000) name, (se(2,k),k=1,nl)
read(2,3000)  name, (mois(2,k),k=1,nl)
write(5,3000) name, (mois(2,k),k=1,nl)
read(2,7000)  name,(ndyr(j),j=1,ns)
write(5,7000) name,(ndyr(j),j=1,ns)
read (2,4000) name,(ainc(j),j=1,ns)
write(5,4000) name,(ainc(j),j=1,ns)
read(2,3000)  name,(ws0(k),k=1,ns)
write(5,3000) name,(ws0(k),k=1,ns)
read(2,3000)  name,(wsm(k),k=1,ns)
write(5,3000) name,(wsm(k),k=1,ns)
read(2,7000)  name,(nws(k),k=1,ns)
write(5,7000) name,(nws(k),k=1,ns)
read (2,4000) name,(sura(j),j=1,ns)
write(5,4000) name,(sura(j),j=1,ns)
read (2,4000) name,(surb(j),j=1,ns)
write(5,4000) name,(surb(j),j=1,ns)
read (2,8000) name,(dbulk(j,1),j=1,8)
write(5,8000) name,(dbulk(j,1),j=1,8)
read (2,8000) name,(dbulk(j,2),j=1,8)
write(5,8000) name,(dbulk(j,2),j=1,8)
read (2,8000) name,sburn
write(5,8000) name,sburn
read (2,4000) name,(crop(j),j=1,ns)
write(5,4000) name,(crop(j),j=1,ns)
read (2,7000) name,(cblock(j),j=1,ns)
writè(5,7000) name,(cblock(j),j=1,ns)
read (2,4000) name,(ysc(j),j=1,ns)
write(5,4000) name,(ysc(j),j=1,ns)
```

```
      read (2,4000) name,(disequ(1,j),j=1,ns)
      write(5,4000) name,(disequ(1,j),j=1,ns)
      read (2,4000) name,(disequ(2,j),j=1,ns)
      write(5,4000) name,(disequ(2,j),j=1,ns)
      do 70 i = 1,3
           read (2,9000) name,(fyr(i,j),j=1,8)
           write(5,9000) name,(fyr(i,j),j=1,8)
   70 continue
      do 80 i = 1,3
           read (2,8000) name,(fload(i,j),j=1,8)
           write(5,8000) name,(fload(i,j),j=1,8)
   80 continue
      read (2,3000) name,(cbd(i),i=1,ns)
      write(5,3000) name,(cbd(i),i=1,ns)
      read (2,3000) name,(vfl(i),i=1,ns)
      write(5,3000) name,(vfl(i),i=1,ns)
      read (2,3000) name,(cfmc(i),i=1,ns)
      write(5,3000) name,(cfmc(i),i=1,ns)
      read (2,3000) name,(vfmc(i),i=1,ns)
      write(5,3000) name,(vfmc(i),i=1,ns)
      read (2,3000) name,(cflm(i),i=1,ns)
      write(5,3000) name,(cflm(i),i=1,ns)
      read (2,3000) name,(csvr(i),i=1,ns)
      write(5,3000) name,(csvr(i),i=1,ns)
      read (2,3000) name,(vsvr(i),i=1,ns)
      write(5,3000) name,(vsvr(i),i=1,ns)
      read (2,3000) name,(bl(i),i=1,ns)
      write(5,3000) name,(bl(i),i=1,ns)
      read (2,8000) name,(binfest(i),i=1,8)
      write(5,8000) name,(binfest(i),i=1,8)
      read (2,9000) name,(ibcycle(i),i=1,8)
      write(5,9000) name,(ibcycle(i),i=1,8)
      read (2,8000) name,(rdelay(i),i=1,8)
      write(5,8000) name,(rdelay(i),i=1,8)

      do 90 i = 1,ns
           if(spp(i) .eq. 'pial') then
                read(2,9100) name,cmax,agecon,dbhmin,birds,spc,spcac,
     &                       pfind,(cyr(j),j=1,4),fmax,cpt,ssc
                write(5,9100) name,cmax,agecon,dbhmin,birds,spc,spcac,
     &                        pfind,(cyr(j),j=1,4),fmax,cpt,ssc
                go to 99
           endif
   90 continue
   99 close(2)
      return

  100 call error(8)
      close(2)
      return

C ####################### FORMATS ######################

 1000 format(a10)
 2000 format(a4)
 3000 format(a10,7f10.3)
 4000 format(a10,7f10.4)
 5000 format(a10,7(9x,a1))
 6000 format(a10,7f10.7)
 7000 format(a10,7i10)
```

```
 8000 format(a10,7f10.4,/,10x,f10.4)
 9000 format(a10,7i10,/,10x,i10)
 9100 format(a10,7f10.1,/,10x,7f10.4)
      END
      SUBROUTINE wrstrs
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C This subroutine computes the growth reduction factor due to          :
C water stress.  This is a value between 0 and 1 and is stored         :
C in the array GRWS(i).                                                :
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      common/oper/ ns,nspan,nruns,clrcut,nwrstr,ifire,sburn,ibr,impb
      common/water/grws(7),ws0(7),wsm(7),nws(7),wr,grdd(7),grbar(7)
      common/hdata/phi,xmbar(8),degd,ainc(7),binfest(8),ibcycle(8),brr
      common/climat/ dmin(7),dopt(7),dmax(7),baset(12),basep(12),baseh
      integer clrcut

      do 10 i=1,ns

C ..... Calculate growth reduction factor for water stress
          if(nwrstr .ne. 0) then
               grws(i)=1.- ( (wsm(i)-wr)/(wsm(i)-ws0(i)) )**nws(i)
               if(grws(i).lt.0.0) grws(i)=0.0
          else
               grws(i) = 1.0
          endif

C ..... Calculate climatic reduction factor using degree-days
        if(degd .gt. dmin(i) .and. degd .lt. dmax(i)) then
            v = (dmax(i) - dopt(i)) / (dopt(i) - dmin(i))
            grdd(i) = ((degd - dmin(i)) * (dmax(i)-degd)**v) /
     &            (((dmax(i)-dopt(i))**v) * (dopt(i) - dmin(i)))
        else
            grdd(i) = 0.0
        endif

   10 continue
      return
      END
      FUNCTION isum(vect,n)
C *********************************************************************
C This function sums all items in vector VECT from 1 to n and        *
C returns the summed number stored in variable ISUM.                 *
C *********************************************************************
      integer vect(n)
      isum= 0
      if (n.le.0) return
      do 10 j= 1,n
           isum= isum+vect(j)
   10 continue
      return
      END
      FUNCTION risk(ck,dbh,j)
C :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C : Function RISK computes the probability of death from fire for     :
C : tree under consideration.  Equation is from Ryan and Rheinhardt   :
C : (1986).  Also presented is Bevins (1978) equation for small re-   :
C : generation.  Major variables are:                                 :
C :   d1,d2,d3 ... coefficients for one year mortality equation       :
C :   bc(j) ...... thickness of bark in cm                            :
C :   c1,c2,c3,c4 ... coefficients for exponential equation.          :
```

```
C ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

      common/mort/ d1(7),d2(7),d3(7),bc(7)
      data d0/12.7/
      data r/10./,c1/1.466/,c2/-1.914/,c3/0.1792/,c4/0.000535/

C ..... Calculate the constants in the mortality equation
      a0 = d1(j)
      a1 = d2(j)*bc(j)
      a2 = d3(j)
      b0 = alog(r)+a0
      b1 = a1+2.*alog(r)/d0
      b2 = -alog(r)/d0**2

C ..... Mortality equation from Ryan and Rhienhardt 1986
        risk= 1./(1.+exp(-(c1+c2*bc(j)*dbh+c3*
     &         (bc(j)*dbh)**(2.0)+c4*ck**(2.0))))

C ***************************************************************
C ..... Previous mortality equation for trees under 5 in DBH ***
C     if (dbh.lt.d0) risk= 1.-1./(1.+exp(b0-b1*dbh-b2*dbh**2.0 *
C    &                      +a2*hs))                          *
C ***************************************************************
      return
      END
      FUNCTION sum(vect,n)
C ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C : Function SUM adds real elements 1 to n of an array.             :
C ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      real vect(n)
      sum= 0.
      if (n.le.0) return
      do 10 j= 1,n
          sum= sum+vect(j)
   10 continue
      return
      END
      FUNCTION itable(t)
C ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C This function computes the various properties of air at a       :
C specified temperature level.                                    :
C ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

      if(t .ge. 0.0 .and. t .lt. 250.0)     itable =  1
      if(t .ge. 250.0 .and. t .lt. 300.0)   itable =  2
      if(t .ge. 300.0 .and. t .lt. 350.0)   itable =  3
      if(t .ge. 350.0 .and. t .lt. 400.0)   itable =  4
      if(t .ge. 400.0 .and. t .lt. 450.0)   itable =  5
      if(t .ge. 450.0 .and. t .lt. 500.0)   itable =  6
      if(t .ge. 500.0 .and. t .lt. 550.0)   itable =  7
      if(t .ge. 550.0 .and. t .lt. 600.0)   itable =  8
      if(t .ge. 600.0 .and. t .lt. 650.0)   itable =  9
      if(t .ge. 650.0 .and. t .lt. 700.0)   itable = 10
      if(t .ge. 700.0 .and. t .lt. 750.0)   itable = 11
      if(t .ge. 750.0 .and. t .lt. 800.0)   itable = 12
      if(t .ge. 800.0 .and. t .lt. 850.0)   itable = 13
      if(t .ge. 850.0 .and. t .lt. 900.0)   itable = 14
      if(t .ge. 900.0 .and. t .lt. 950.0)   itable = 15
      if(t .ge. 950.0 .and. t .lt. 1000.0)  itable = 16
      if(t .ge. 1000.0 .and. t .lt. 1100.0) itable = 17
```

```
if(t .ge. 1100.0 .and. t .lt. 1200.0) itable = 18
if(t .ge. 1200.0 .and. t .lt. 1300.0) itable = 19
if(t .ge. 1300.0 .and. t .lt. 1400.0) itable = 20
if(t .ge. 1400.0)                     itable = 20
return
END
```

APPENDIX B: PRINTOUT OF THE EXTERNAL INPUT FILE TREE.DAT, WHICH CONTAINS VARIOUS SPECIES AND SITE PARAMETERS FOR EQUATIONS IN FIRESUM

Variables not defined in text are described in Keane and others (1989a) and Keane and others (1989b).

```
pipo
abgr
psme
pico
laoc
abla
pien
$$$$$$$$$$
hm            6562.500  5333.700  5715.000  4115.000  6857.500  4175.700  5456.700
dm             250.500   139.400   208.840   110.000   250.000   126.700   234.400
agemx          450.000   275.000   350.000   220.000   450.000   180.000   320.000
dmin          2249.900  2496.600  1810.400  1215.300  1817.400   801.800   801.400
dopt          4010.000  4200.000  4200.000  4200.000  4200.000  3800.000  4200.000
dmax          8608.000  7194.000  7194.000  6500.000  7194.000  6200.000  6200.000
spm              1.000     3.000     6.000     2.000     4.000     3.000     5.000
spm-cont         5.000
aside        3.5400000  2.040000  2.850000 3.5400000 3.5400000  2.040000 2.0400000
c                2.074     1.608     1.582     1.882     1.679     1.255     1.710
alpha        0.2680000 1.3090000 1.1370000 0.1220000 0.4370000 7.3450000 1.0400000
sigma           57.600    72.900    69.100    64.700   184.000    70.000    54.200
ap           0.5580000 1.5920000 0.4840000 0.4930000 0.3470000 0.5970000 0.5780000
betap       -0.0475000 0.0590000-0.0210000 0.0117000-0.0434000-0.0425000-0.0325000
cext            0.4260    0.5250    0.5250    0.4260    0.4260    0.4260    0.4260
cext cont       0.525
ishade               I         T         M         I         I         T         M
imoist               T         I         T         T         I         I         I
xmbar           0.0071    0.0089    0.0149    0.0074    0.0091    0.0107    0.0083
xmbar cont      0.0111
crat         0.4000000  0.800000  0.800000 0.4000000 0.4000000  0.800000 0.8000000
mext              .250
amc              1.651     1.651     1.651     1.651     1.651     1.651     1.651
bmc              0.493     0.493     0.493     0.493     0.493     0.493     0.493
cmc             19.350    19.350    19.350    19.350    19.350    19.350    19.350
dmc             10.880    10.880    10.880    10.880    10.880    10.880    10.880
mmc               .320      .320      .320      .320      .320      .320      .320
tmc             24.000
rhop              .510      .390      .390      .390      .510      .510      .510
bulk            0.0158    0.0088    0.0068    0.0080    0.0115    0.0071    0.0126
bulk cont       0.0080
lhv          18586.700 18586.700 18586.700 18586.700 18586.700 18586.700 18586.700
mps-fg1         57.410     8.890     3.480     0.950     3.156   91.8560    3.0000
mps-fg2         57.410    11.760     2.880     0.980     3.156   91.8560    3.0000
mps-fg3         57.410    16.000     3.077     0.980     3.156   91.8560    3.0000
mps-fg4         57.410    16.000     3.077     0.980     3.156   91.8560    3.0000
mps-fg5         57.410    16.000     3.077     0.980     3.156   91.8560    3.0000
mps-fg6         57.410    16.000     3.077     0.980     3.156   91.8560    3.0000
mps-fg7         57.410    11.760     2.880     0.980     3.156   91.8560    3.0000
mps-fg8         57.410    11.760     2.880     0.980     3.156   91.8560    3.0000
st                .055      .055      .055      .055      .055      .055      .055
se                .010      .010      .010      .010      .010      .010      .010
dkl              .1116     .0667     .1167     .1116     .2000     .0667     .0667
ltd              .5500     .6500     .6550     .6600     .8500     .6500     .6500
dkf              .0575     .0339     .0339     .0440     .1310     .0339     .0339
dkd              .2210     .2210     .2210     .2210     .3210     .2210     .2210
```

ffl	.1200	.1200	.1200	.1200	.1200	1.0000	.1200
d1	.1688	.1688	.1688	.1688	.1688	.1688	.1688
d2	1.969	1.969	1.969	1.969	1.969	1.969	1.969
d3	.306	.306	.306	.306	.306	.306	.306
bc	.070	.033	.065	.014	.071	.015	.022
rhop	0.513	0.513					
bulk	0.001	0.001					
lhv	18595.000	18595.000					
mps	49.200	91.860					
st	.055	0.055					
se	.010	0.010					
mois	1.000	1.500					
ndyr	4	7	5	3	1	7	6
ainc	0.0120	0.0050	0.0070	0.0150	0.0160	0.0080	0.0080
ws0	.25	.47	.32	.38	.38	.65	.65
wsm	1.	1.	1.	1.	1.	1.	1.
nws	2	2	2	2	2	2	2
sura	10.5900	40.0100	38.6900	14.1200	20.1700	40.0100	40.0100
surb	2.7400	5.1150	4.2400	2.2800	5.5900	6.1150	6.1150
dbulk(1,i)	15.8000	36.2000	41.6000	21.9000	25.3000	35.0000	43.3000
cont	38.1000						
dbulk(2,i)	76.9000	76.9000	145.7900	76.9000	110.6300	110.6300	139.4800
cont	142.7000						
sburn	0.7500						
crop	0.3950	0.3330	0.4460	0.3180	0.3680	0.3330	0.1670
cblock	2	2	1	2	2	2	3
ysc	20.0000	25.0000	20.0000	15.0000	25.0000	25.0000	25.0000
disequ(1j)	13.1251	13.4099	14.1251	12.6760	14.3257	13.4099	12.7470
disequ(2j)	0.0255	0.0183	0.0222	0.0376	0.0148	0.0183	0.0251
fyr-1hr	40	40	40	40	30	30	40
fyr-1hr	50						
fyr-10hr	40	40	40	40	30	30	40
fyr-10hr	50						
fyr-100hr	40	40	40	40	30	30	40
fyr-100hr	50						
fload-1hr	0.0210	0.1350	0.2710	0.0638	0.0520	0.0520	0.1776
fload-1hr	0.0748						
fload-10hr	0.0833	0.2650	0.1548	0.2619	0.1879	0.1879	0.4294
fload-10hr	0.1960						
fload100hr	0.1546	1.6475	0.1055	0.5484	0.5635	0.5635	4.7022
fload100hr	0.5459						
cbd	1.106	0.577	0.304	1.202	1.042	.000	.000
vfl	1.058	0.593	0.561	0.721	0.529	.000	.000
cfmc	1.050	1.050	1.050	1.050	1.050	.000	.000
vfmc	.100	.100	.100	.100	.100	.000	.000
cflm	1.000	1.000	1.000	1.000	1.000	.000	.000
csvr	60.700	64.700	184.000	72.900	54.200	.000	.000
vsvr	10.000	20.000	10.000	30.000	30.000	.000	.000
bl	0.1	0.10	0.1	0.100	0.100	0.100	0.100
binfest	0.660	0.800	0.800	0.450	0.640	0.660	0.440
bin(cont)	0.800						
ibcycle	10	10	10	10	10	10	10
ibcycle c	10						
rdelay	10.000	25.000	8.000	11.000	12.000	8.000	15.000
rdelay	20.000						
cmax	600.0	60.0	20.0	3.0	58.8	3.7	0.800
icyr	0.3521	0.4673	0.7825	1.0000	7.0	60.0	0.120
end							

APPENDIX C: PRINTOUT OF THE EXTERNAL INPUT FILE SITE.DAT, WHICH CONTAINS VARIOUS SITE PARAMETERS FOR EQUATIONS IN FIRESUM

Variables not defined in text are described in Keane and others (1989a) and Keane and others (1989b).

```
baset       17.8 21.1 23.5 31.7 40.1 51.0 64.0 63.0 55.0 38.9 26.5 21.4
basep       6.12 4.69 3.90 4.10 3.65 2.81 1.92 2.56 2.00 2.94 4.38 5.62
baseh        8000.000
excess          0.250
phi             1.000
text          133.300        site = Sabe Mountain
rock            0.100
elev         7200.000
ifg                 2
till            3.000
rh              40.00
wind            3.200
ttheta          0.26
t              19.000
pltsiz        400.000
emc             0.080     0.080     0.080     0.080     0.100     0.080     0.100
dmoist          0.7500
brr             0.01
END
```

APPENDIX D: PRINTOUT OF THE EXTERNAL INPUT FILE CONTRL.DAT, WHICH CONTAINS VARIOUS INITIAL STAND PARMETERS THAT ARE USED TO CREATE THE SIMULATION STAND IN FIRESUM

Variables not defined in text are described in Keane and others (1989a) and Keane and others (1989b).

```
nspan          500
nruns            5
clear cut        0                  SITE: ONE HORSE RIDGE CLIMAX STAND
ifire          600
iblist         600
ibeetle        600
dsize          20.0   20.0   20.0   20.0   20.0   20.0   20.0
nwrstr           1
nbins           10
width          5.0
count 1         18      0      0      4      0
count 2          3      0      0      1      0
count 3          3      0      0      0      0
count 4          3      0      0      0      0
count 5          6      0      0      0      0
count 6          7      0      0      0      0
count 7          3      0      0      0      0
count 8          3      0      0      0      0
count 9          0      0      0      0      0
count10          2      0      0      0      0
age   1         38      0      0     65      0
age   2         96      0      0     53      0
age   3         60      0      0      0      0
age   4         70      0      0      0      0
age   5        300      0      0      0      0
age   6        250      0      0      0      0
age   7        350      0      0      0      0
age   8        370      0      0      0      0
age   9          0      0      0      0      0
age  10        450      0      0      0      0
END
```


*U.S. GOVERNMENT PRINTING OFFICE: 1989-0-673-039/01006

Keane, Robert E.; Arno, Stephen F.; Brown, James K. 1989. FIRESUM—an ecological process model for fire succession in western conifer forests. Gen. Tech. Rep. INT-266. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 76 p.

Describes an ecological process model of succession that simulates long-term stand dynamics in forests of the Northern Rocky Mountains. This model is used to evaluate the effects of various fire regimes, including prescribed burning and fire suppression, on the vegetation and fuel complex of a simulation stand. This report documents the model FIRESUM (a **FIRE SU**ccession Model), examples of model output, and sensitivity analysis and validation results.

KEYWORDS: fire effects, fire regime, succession, documentation, computer program, wildland fire, fire management, fire ecology, forest succession, fire effects, fire regime

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The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

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